Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium

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ACRONYMS AND ABBREVIATIONS

AIRS – Aerometric Information Retrieval System
Am – americium
AM – arithmetic mean
AMAD – activity median aerodynamic diameter
AME – Actinide Migration Evaluation
ARARs – applicable or relevant and appropriate requirements
BLUP – best linear unbiased predictor
BTM – best tracer method
CDF – cumulative distribution function
CDPHE – Colorado Department of Public Health and Environment
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CF – conversion factor
Ci – Curie
cm – centimeter
CR – concentration ratio
CSF – cancer slope factor
CSFII – Continuing Survey of Food Intakes by Individuals
CTE – central tendency exposure
CY2000 – Calendar Year 2000
DCF – dose conversion factor
DOE – United States Department of Energy
DU – depleted uranium
DWC – dry-to-wet weight conversion
ECDF – empirical cumulative distribution function
ED – exposure duration
EDF – empirical distribution function
EF – exposure frequency
EFH – Exposure Factors Handbook
EPA – United States Environmental Protection Agency
ET – exposure time
EU – enriched uranium
f1 – gastrointestinal uptake fraction
F_{in} – indoor time fraction
F_{out} – outdoor time fraction
F/S – food-to-soil ratio
GI – gastrointestinal
GM – geometric mean
GSD – geometric standard deviation
HEAST – Health Effects Assessment Summary Tables
ICRP – International Commission on Radiological Protection
IdF – indoor time fraction
IRa – inhalation rate
IRIS – Integrated Risk Information System
IRs – soil ingestion rate

kg – kilogram
MCA – Monte Carlo analysis
ML – mass loading
mrem – millirem
MRI – Midwest Research Institute
NCP – National Contingency Plan
NCRP – National Counsel on Radiation Protection
NDMC – National Drought Mitigation Center
NFCS – Nationwide Food Consumption Survey
NRC – Nuclear Regulatory Commission
NRPB – National Radiological Protection Board
OdF – outdoor time fraction
OU – operable unit
pCi – picoCuries
pCi/g – picoCuries per gram
PDF – probability density function
PM – particulate matter
PPRG – Programmatic Preliminary Remediation Goals
PRA – probabilistic risk assessment
Pu – plutonium
RAAMP – Radioactive Ambient Air Monitoring Program
RAC – Risk Assessment Corporation
RAGS – Risk Assessment Guidance for Superfund
rem – Roentgen-equivalent man
RESRAD – Residual Radioactivity Model
RFCA – Rocky Flats Cleanup Agreement
RfD – Reference Dose
RFI/RI – Resource Conservation and Recovery Act Facility Investigation/Remedial Investigation
RI/FS – remedial investigation and feasibility study
RMA – Rocky Mountain Arsenal
RME – reasonable maximum exposure
ROP – residential occupancy period
RSAL – radionuclide soil action level
RSD – relative standard deviation
SD – standard deviation
SF_{oral} – oral slope factor
SIR – soil ingestion rate
SISF – soil ingestion slope factor
SOR – sum-of-ratios
TCR – target cancer risk
TF – soil-to-plant transfer factor
TSP – total suspended particulates
Type F – fast absorption from the lung to the blood for inhalation
Type M – medium absorption from the lung to the blood for inhalation
Type S – slow absorption from the lung to the blood for inhalation
U – uranium

μ – one part in one million parts
μg – micrograms
μg/g – micrograms per gram
μg/m³ – micrograms per cubic meter
μm – micrometers
UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation

1.0 EXECUTIVE SUMMARY

The United States Department of Energy (DOE), the U S Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE) are calculating surface radionuclide soil action levels (RSALs) for plutonium, americium, and uranium that will guide soil remediation during the accelerated cleanup of Rocky Flats These action levels will replace the levels established by the DOE, the EPA, and the CDPHE (the agencies) in the 1996 Rocky Flats Cleanup Agreement (RFCA)

This report, Task 3, is the last of five reports that were prepared during this review and represents the culmination of the information developed in the other four reports These other reports are Task 1 Regulatory Analysis, Task 2 Computer Model Selection, Task 4 New Science, and Task 5 Determining Cleanup Goals at Radiologically-Contaminated Sites

The Task 3 Report discusses the exposure scenarios that the agencies are using for the calculation of the surface RSALs, as well as the methods of calculation, the associated input variables, and the results of the calculations and effects of uncertainties Dose calculations were performed using the RESRAD 6 0 (Residual Radioactivity) model and risk calculations were performed following EPA's Standard Risk Methodology Four exposure scenarios are addressed in this report Wildlife Refuge Worker, Rural Resident, Open Space User, and Office Worker A fifth scenario, the Residential Rancher is examined to illustrate the comparability of analytical approaches between this work and earlier work performed by Risk Assessment Corporation (RAC) Plutonium (Pu), americium (Am), and uranium (U) (depleted and enriched) activity concentrations in surface soil were calculated for a 25-millirem (mrem) annual dose and for concentrations within EPA's target risk range of one in ten thousand to one in one million (10^{-4} to 10^{-6}) cancer incidences for various land use scenarios In addition, non-cancer risk calculations were performed with EPA's Standard Risk Methodology for total uranium In order to account for the contribution to dose and risk from multiple radionuclides present in the environment, the RSALs were adjusted with a sum-of-ratios method The sum-of-ratios method is presented in Chapter 5 of this report

This document has undergone extensive technical peer review and comments have been incorporated The agencies will select RSALs based on the results of the analyses in this final report The analyses will also provide a basis for establishing final cleanup levels at Rocky Flats, taking into account other factors, such as the effort to clean up "as low as reasonably achievable" and impacts to long-term site stewardship

The RSAL Working Group recommends that the final RSALs be selected from the probabilistic RSALs calculated for the Wildlife Refuge Worker and the Rural Resident scenarios The outcome of the probabilistic risk assessment for each scenario is a distribution of potential health-protective RSALs Based on the evaluation of variability and uncertainty performed in Chapter 7 of this report, the RSAL Working Group recommends that RSAL values between the 10^{th} and 5^{th} percentiles of the distributions be selected as representative of the reasonable maximum exposed (RME) individual at the Rocky Flats site

Tables 1-1, 1-2, and 1-3 give examples of adjusted RSALs for plutonium, americium, and uranium selected from the 5th percentile of the RSAL distributions using the probabilistic dose and risk approaches for the Wildlife Refuge Worker and Rural Resident scenarios For the Office Worker and Open Space User scenarios, the RSALs presented below were calculated using a point estimate approach The RME corresponds to the single point estimate RSAL

Table 1-1 Dose- and risk-based RSALs for plutonium in surface soil adjusted by the sum-of-ratios (SOR) method (pCi/g) [1]

Land Use Scenario	Target Risk Levels			25-mrem Annual Dose
	10^{-4}	10^{-5}	10^{-6}	
Wildlife Refuge Worker[2]	908	91	9	780
Rural Resident – adult[2]	183	18	2	231
Rural Resident – child[2]				251
Office Worker[3]	655	65	7	1,598
Open Space User – adult[3]	960	96	10	3,617
Open Space User – child[3]				1,205

[1]Accounts for additional activity from Am using a sum-of-ratios method, and assumes that the Am Pu activity ratio equals 0 182 and that only Am and Pu is present
[2]Probabilistic results – reasonable maximum exposure (RME) corresponds to the 5th percentile of the RSAL distribution
[3]Point estimate results – RME corresponds to the single point estimate RSAL

Table 1-2 Dose- and risk-based RSALs for americium in surface soil adjusted by the SOR method (pCi/g) [1]

Land Use Scenario	Target Risk Levels			25-mrem Annual Dose
	10^{-4}	10^{-5}	10^{-6}	
Wildlife Refuge Worker[2]	165	17	2	142
Rural Resident – adult[2]	33	3	0 3	42
Rural Resident – child[2]				46
Office Worker[3]	119	12	1	291
Open Space User – adult[3]	175	17	2	658
Open Space User – child[3]				219

[1]Accounts for additional activity from Pu using a sum-of-ratios method, and assumes that the Am Pu activity ratio equals 0 182 and that only Am and Pu are present
[2]Probabilistic results – RME corresponds to the 5th percentile of the RSAL distribution
[3]Point estimate results – RME corresponds to the single point estimate RSAL
SOR = sum-of-ratios

Table 1-3 Probabilistic risk- and dose-based RSALs for uranium in surface soil adjusted by the SOR method (pCi/g and μg/g) [1 2]

Radionuclide	Land Use Scenario	10^{-4} Target Risk		Annual Dose	
		DU[3]	EU[4]	DU[3]	EU[4]
U-238	Wildlife Refuge Worker	1,636	36	915	81
	Rural Resident – adult	77	3	173	11 3
	Rural Resident – child			194	12 6
U-235	Wildlife Refuge Worker	23	54	13	122
	Rural Resident – adult	1	5	2 5	17
	Rural Resident – child			2 8	19
U-234	Wildlife Refuge Worker	678	817	379	1,826
	Rural Resident – adult	32	72	72	254
	Rural Resident – child			80	284
Uranium (non-cancer[2])	Wildlife Refuge Worker	2,750		NA	NA
	Rural Resident	458			

[1]Probabilistic approach, risk to reasonable maximum exposed (RME) individual corresponds to the 5th percentile of the RSAL distribution
[2]Units for RSALs for isotopes 238, 235, and 234 are pCi/g, units for RSALs for non-cancer risk are μg/g
[3]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29 for U-238 U-235 U-234
[4]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90 for U-238 U-235 U-234
NA = not applicable for the dose-based calculations, DU = depleted uranium, EU = enriched uranium,
SOR = sum-of-ratios

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2.0 INTRODUCTION FOR CALCULATION OF SURFACE RSALS FOR PLUTONIUM AND AMERICIUM

The agencies are proposing new RSALs for surface soil for plutonium, americium, and uranium to guide the cleanup at Rocky Flats These RSALs will replace those levels established in 1996 (current RSALs) The RSALs are the activity concentrations of radionuclides in soils that, if exceeded, trigger an evaluation, a remedial action, or a management action New RSALs are being proposed for a number of reasons, including

- The RFCA requires periodic review of action levels
- The current RSALs have been controversial among local governments and community members
- A draft EPA radiation site cleanup rule that was used as the basis for the current RSALs was never formally proposed or promulgated
- New technical information relevant to the RSALs has become available since the current RSALs were developed in 1996, including an independent calculation of RSALs by RAC
- An updated version of the computer code was used to calculate radiation dose effects (RESRAD 6 0)
- New data and guidance are now available for the use of probabilistic distributions for certain sensitive variables

This assessment discusses the exposure scenarios that the agencies are using for the calculation of new RSALs, as well as the methods of calculation, the associated exposure variables and parameter estimates, and the results of the calculations Four exposure scenarios are addressed in this report Wildlife Refuge Worker, Rural Resident, Open Space User, and Office Worker A fifth scenario, the Resident Rancher, was exercised to compare modeling methodologies employed by RAC and by the agencies for this analysis

The agencies chose the Wildlife Refuge Worker scenario as the most likely land use scenario because it appeared likely that Rocky Flats would be designated a national wildlife refuge On December 28, 2001 a bill was signed into law designating Rocky Flats as a national wildlife refuge The Rural Resident scenario was chosen because the agencies believe that if institutional controls fail in the future, a residential scenario represents a foreseeable land use Calculations based on the office worker and the open space users were performed because the RFCA signed in 1996 listed those scenarios as anticipated future uses These scenarios were evaluated primarily to provide a comparison to the 1996 RSALs The agencies calculated a value for a Resident Rancher scenario using the same parameter values as RAC (wherever possible) for the purpose of comparing the model software they employed to that used by the agencies and at the request of members of the public, results of this latter calculation are presented as an appendix

The primary regulatory bases for the Rocky Flats RSALs stem from the Nuclear Regulatory Commission (NRC) decommissioning rule and the Superfund law (Comprehensive Environmental Response, Compensation, and Liability Act) (CERCLA) For a more complete discussion of the regulatory bases, refer to the Task 1 Report The NRC rule says that the site should be cleaned up so that a future user will not receive a dose greater than 25 mrem/yr and that residual radioactivity is reduced to a level "as low as reasonably achievable" Since the NRC rule is relevant to and appropriate for the cleanup of Rocky Flats, the agencies performed dose assessments to develop potential RSAL values that correspond to a dose of 25 mrem/yr RESRAD 6 0, which is capable of probabilistic calculations, is the computer model used for that assessment Earlier versions of RESRAD were used by the agencies in 1996 and later by RAC Since the 25-mrem/yr dose limit may not meet the protective risk range spelled out in the CERCLA of one in ten thousand to one in a million (10^{-4} to 10^{-6}), the agencies also developed potential RSAL values based on risk using the EPA's Standard Risk equations

Principal changes in methodology between the 1996 calculations and the current effort are the use of probabilistic methodologies in the calculations in contrast to the purely deterministic methods employed in 1996 Additionally, updated dose conversion factors (dose conversion factors) and cancer slope factors were employed, and a comprehensive uncertainty analysis was performed Differences between a point estimate analysis and a probabilistic analysis are summarized as follows

- <u>Point estimate (deterministic)</u> – Single parameter values are used in an equation to calculate a value, in this case a concentration of radionuclides in the soil that equates to a target dose level or risk level (e g , 25 mrem/yr or 10^{-4}, respectively),

- <u>Probabilistic</u> – For highly sensitive exposure variables, distributions of values are substituted for single point values and the equation is repeatedly solved with computer software that randomly chooses different values from the input distributions for each iteration Hundreds or thousands of iterations are performed to produce an output that is itself a distribution In this case that output distribution represents various levels of contamination that could result in a target dose or risk level depending on the variability of important exposure variables such as inhalation rate and time spent on site

The agencies spent considerable effort in determining the sensitive exposure variables, evaluating if variables should be described by a point estimate or probability distribution, and entering those inputs into the selected dose and risk modeling equations This report provides the results of RSAL calculations for the five scenarios listed above For the Office Worker, Open Space User, Wildlife Refuge Worker, and Rural Resident scenarios, results are provided in picoCuries/gram (pCi/g) of soil that equate to risk levels of 10^{-4}, 10^{-5}, and 10^{-6} and to a target dose of 25 mrem/yr

Chapter 1 has given the executive summary for the report, including the most relevant RSAL calculations for each scenario

Chapter 2 provides a brief review of the reasons for calculating new RSALs for plutonium and americium at Rocky Flats, as well as an introduction to the point estimate and probabilistic assessment approaches used to calculate the new RSALs

Chapter 3 provides detailed discussions of the four land use scenarios employed for both dose and risk assessments Wildlife Refuge Worker, Rural Resident, Open Space User, and Office Worker

Chapter 4 gives an overview of the methodology of the dose and risk analysis, including the calculation of an RSAL, methods and preliminary results of sensitivity analysis, and the process for developing probability distributions for input variables In addition, details are provided on the derivation of the mass loading distribution, and the rationale for the selection of cancer slope factors and the dose conversion factors

Chapter 5 presents the results from the dose- and risk-based calculations of RSALs for americium and plutonium, including calculations based on individual radionuclides and the adjusted RSALs using the sum-of-ratios approach

Chapter 6 presents RSAL calculations for uranium isotopes Uranium requires additional considerations because of an increase in the uptake of uranium by plants, the potential for non-cancer renal toxicity, the variability of isotopic ratios, and the sensitivity of the area of the contaminated zone variable This requires an analysis based on the likely anthropogenic mix of uranium isotopes, in addition to the assessment of individual isotopic contributions to dose and risk

Chapter 7 provides a discussion of the variability and uncertainty of the dose and risk assessments, and the utility of this information in the selection of an RSAL that is protective of the RME individual

The following appendices supply information about the derivation of point estimates and probability distributions, methodologies for implementing the dose- and risk-based calculations of RSALs, relevant site-specific data, and more detailed modeling results

- Appendix A Justification and Supporting Documentation for Input Parameters
- Appendix B Description of the EPA Standard Risk Equations
- Appendix C Microsoft Excel Spreadsheets for Risk-based RSAL Calculations and Instructions for Use
- Appendix D Complete RESRAD Input Parameters for Dose Calculations
- Appendix E RESRAD Results (on CD-ROM)
- Appendix F PM-10 Air Monitoring Data from Rocky Flats and the State of Colorado
- Appendix G RESRAD Results for the Resident Rancher Scenario
- Appendix H Tornado Plots Showing Probabilistic Sensitivity Analysis Results for Risk-based RSALs
- Appendix I Response to Comments

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3.0. SCENARIO SELECTION FOR DOSE AND RISK ASSESSMENTS

This section describes each of the land use scenarios that were evaluated for this study A comparison of the features of each of the scenarios is summarized in Table 3-2 Physiological and site-specific physical exposure variables common to all scenarios are described separately in Chapter 4 For each scenario pathway, a sensitivity analysis was performed for individual exposure pathways, as well as for the combination of all potentially active pathways to identify those exposure variables with the greatest influence on the dose and risk estimates Parameter sensitivity was also evaluated within each pathway and for the combined pathways of the Rural Resident scenario, this scenario contains all the pathways whose parameters are evaluated in this assessment

Figures 3-1 through 3-4 are conceptual site models that delineate potential pathways for exposure to radiological contaminants for each exposure scenario The conceptual site models identify which of the exposure pathways are considered complete, i e , capable of transferring harmful effects from radionuclides in surface soils to exposed individuals The complete pathways are further identified as either significant or insignificant, based on their contribution to the calculated dose or risk An exposure pathway describes the course that a contaminant takes from a source to an exposed individual An exposure pathway is considered to be complete when the following factors are present

- A source of potentially toxic contaminants and mechanism of release,
- A retention or transport medium,
- A point of potential human contact with the contaminated medium, and
- An exposure route for chemical intake by a receptor (e g , ingestion, inhalation, and dermal contact) at the exposure point

If one of these factors is missing, the exposure pathway is incomplete and does not pose a health hazard Table 3-1 compares these pathways for the exposure scenarios

Table 3-1 Summary of complete pathways for each exposure scenario

Exposure Pathways	Exposure Scenarios			
	Wildlife Refuge Worker	Rural Resident	Open Space User	Office Worker
Surface water ingestion	I	I	I	IC
Surface water-dermal contact	I	I	I	IC
Soil ingestion	S	S	S	S
Soil-dermal contact	I	I	I	I
Sediment ingestion	I	I	I	IC
Sediment-dermal contact	I	I	I	IC
Plant ingestion	IC	S	IC	IC
Dust inhalation	S	S	S	S
External gamma irradiation	S	S	S	S

S = significant pathway, I = insignificant pathway, IC = incomplete pathway

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The agencies chose the Wildlife Refuge Worker scenario because it appeared likely that Rocky Flats would be designated a national wildlife refuge Should institutional controls fail in the future, a Residential scenario is a foreseeable land use Calculations based on the office worker and the open space user were performed because the Rocky Flats Cleanup Agreement, signed in 1996, listed those scenarios as anticipated futures uses These scenarios were evaluated primarily to provide a comparison to the 1996 RSALs The agencies also calculated a value for a Resident Rancher scenario (see Appendix G) using the same parameter values as RAC, wherever possible, for the purpose of comparing the model software used by RAC to that used by the agencies, and at the request of members of the public

Table 3-2 Comparison of exposure scenarios evaluated in this risk assessment report [1]

Scenario Features	Wildlife Refuge Worker	Office Worker	Open Space User	Rural Resident
Radiation dose limit	25 mrem/yr	25 mrem/yr	25 mrem/yr	25 mrem/yr
Risk level	Calculated at 10^{-4}, 10^{5}, and 10^{-6} target levels	Calculated at 10^{4}, 10^{5}, and 10^{6} target levels	Calculated at 10^{-4}, 10^{5}, and 10^{6} target levels	Calculated at 10^{4}, 10^{5}, and 10^{-6} target levels
Time on-site	Variable up to 250 days/yr, 8 hours per day, 5 days per week	250 days/yr, 8 hours per day, 5 days a week	100 times per year and 2 5 hours per visit	Variable up to 350 days/yr at 24 hours per day
Percent of on-site time outdoors	50%	0%	100%	Up to 15%
Life time at the site	Up to 40 years	25 years	30 years	Up to 87 years
Cover over contaminated soils	Native vegetation	Native vegetation	Native vegetation	Native vegetation
User activity level	Sedentary and active	Sedentary	Active	Sedentary and active
On-site fruits or vegetables	None	None	None	Yes
On-site drinking water source	None	None	None	None
Windows and doors	Closed with ventilation	Closed with ventilation	No indoor exposure	Open during warm weather
Indoor exposure rate from gamma radiation	40% of outdoor rate	40% of outdoor rate	None	40% of outdoor rate
Increased airborne contamination after fires	Yes	Yes	Yes	Yes

[1]This table compares the physical conditions that make up each scenario and affect the exposure that users would receive While there are differences between all of the scenarios, there are also conditions that the scenarios have in common

Note See Appendix A for a detailed description of the probabilistic distributions
See Appendix C for the risk-based spreadsheet
See Appendix D for the detailed descriptions of the values used in RESRAD

3.1 SCENARIO DESCRIPTIONS

3 1.1 WILDLIFE REFUGE WORKER SCENARIO

This scenario assumes that a national wildlife refuge will be established on the acreage that is now Rocky Flats as a result of federal legislation signed by the President on December 28, 2001 (Public Law 107-107) In accordance with this legislation for the Rocky Flats Wildlife Refuge, the purposes of the proposed refuge are (1) restoring and preserving native ecosystems, (2) providing habitat for, and population management of, native plants and migratory and resident wildlife, (3) conserving threatened and endangered species, and (4) providing opportunities for compatible scientific research Given this legislation and the widespread community preference for preservation of Rocky Flats as open space, the Wildlife Refuge Worker scenario represents the most likely future use of Rocky Flats

The scenario predicates that the refuge headquarters, which could include office buildings and equipment storage and maintenance shops, would be placed in that portion of Rocky Flats where soils contain residual contamination It is assumed no visitor center would be developed at Rocky Flats, and facilities for childcare are not included as a part of the refuge building complex

This scenario provides that the wildlife refuge workers may be scientists, maintenance workers, equipment operators, or other occupations that require the worker to spend 100% of work time on-site and a significant fraction of that time (50%) outdoors The wildlife refuge workers would spend all of their time on the contaminated area Refuge workers can be described as individuals who work 8 hours per day, 5 days per week, and 40 to 50 weeks each year (average of 45 weeks) The area is considered to be undeveloped surface soil with only vegetative cover over the contaminated soils except where buildings are present Cover from lawn grasses, which would reduce exposure, has not been used in this or any other scenario Refuge workers would perform a variety of activities where they could be directly exposed to surface or subsurface soil, breathe contaminated dust, and be exposed to external gamma radiation Some of the tasks they do would involve physical labor resulting in an increased breathing rate and soil disturbing activities, which results in increased dust inhalation and increased soil ingestion Windblown contaminated soil particles may be significantly increased during some days due to grass fires that have occurred on contaminated parts of the refuge

In this scenario the windows and doors of the buildings would be closed during cooler seasons, providing partial shielding from dust During time indoors, the refuge worker would be partially shielded by the building from gamma radiation There is no onsite source of fruits, vegetables, or drinking water that would be consumed by refuge workers

The conceptual site model in Figure 3-1 evaluates all of the possible pathways for contamination to reach this receptor and illustrates which pathways are accessible to the receptor

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WILDLIFE REFUGE WORKER EXPOSURE SCENARIO

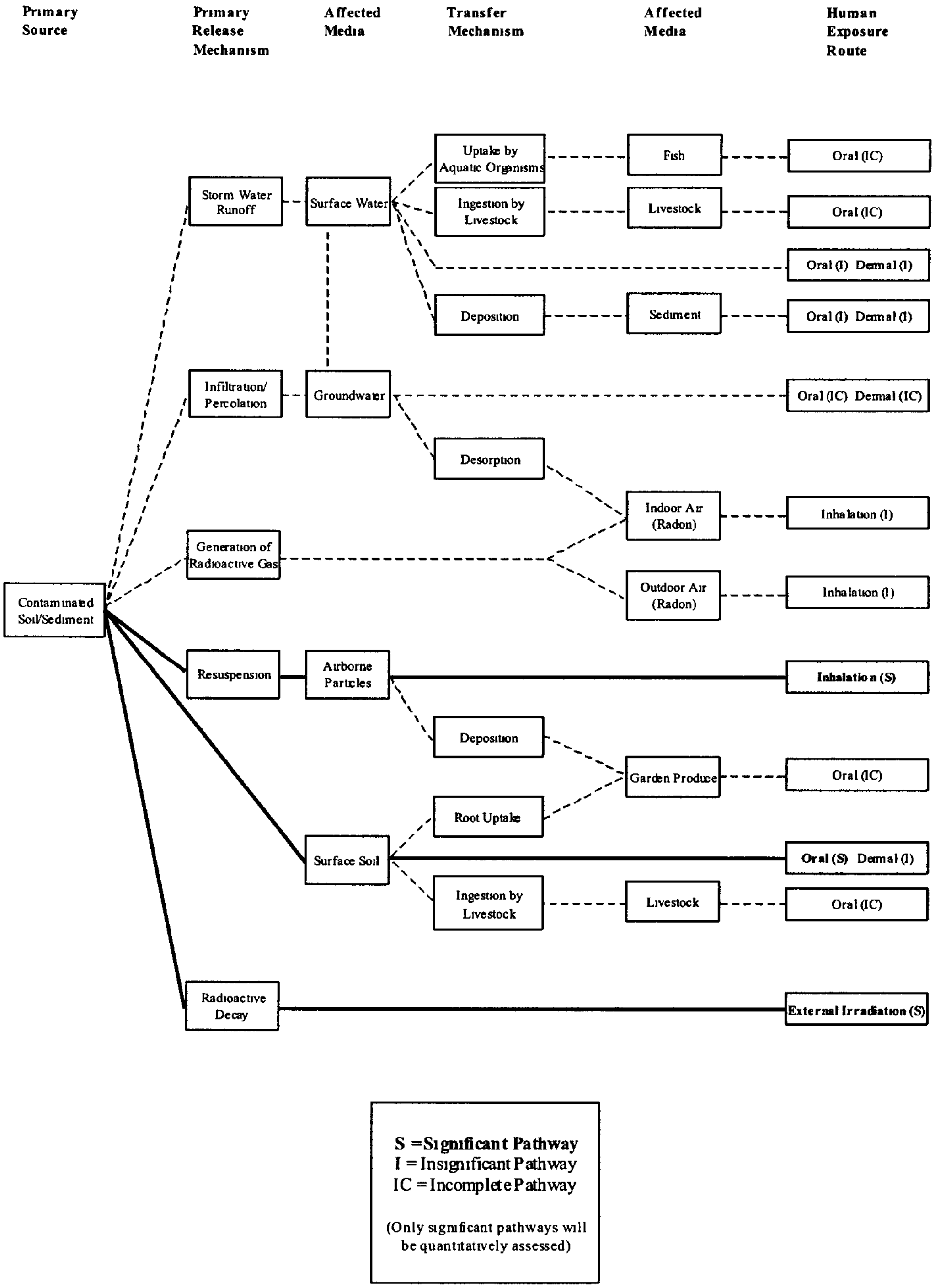

Figure 3-1 Conceptual Site Model for Wildlife Refuge Worker scenario

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Exposure Pathways for the Wildlife Refuge Worker Scenario

Exposure pathways for the wildlife refuge worker are identified in the conceptual site model in Figure 3-1 There are three exposure pathways that are considered complete and potentially significant for the Wildlife Refuge Worker scenario ingestion of contaminated soil, inhalation of contaminated dust, and external exposure to gamma radiation from contaminated surface soil These three exposure pathways were quantitatively assessed in deriving an RSAL for the wildlife refuge worker

Pathways that would not be complete or significant for the worker have been excluded For instance, the consumption of contaminated garden fruits and vegetables and the consumption of contaminated shallow groundwater as drinking water have been excluded for the Wildlife Refuge Worker scenario because these pathways are not viable While it could be argued that a worker could discover wild fruits or ingest surface water on the refuge, such incidents would be rare and are considered unrealistic for this exposure scenario Pathways requiring consumption of meat, milk, or aquatic food produced on the refuge (none realistically available), or those requiring exposure to radon, tritium, and carbon-14 (attributable only to natural background) have also been excluded

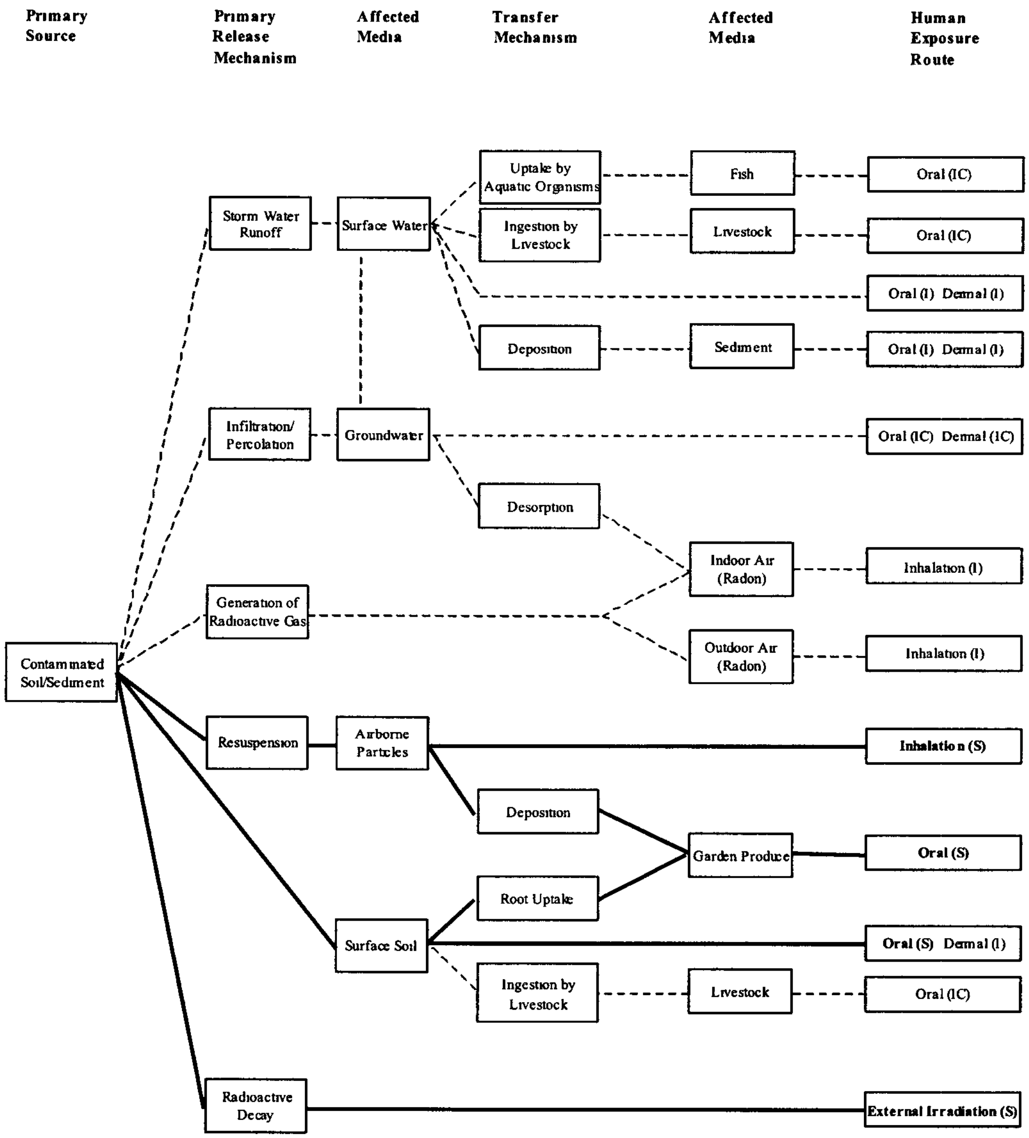
3 1.2 RURAL RESIDENTIAL SCENARIO

A Rural Residential scenario was chosen to represent a future user of the Rocky Flats Industrial Area in the event that institutional controls fail or are not present to prevent the occupation of areas with contaminated soils Residents considered in this scenario are adults and children who would spend most of their time on-site and up to 15% of their time outdoors The indoor exposure rate from gamma radiation would be reduced by the building structures, and the contaminated dust present in outdoor air would be present in indoor air at a reduced concentration commensurate with having windows closed during cool weather Dust in air would be increased for periods following fires that burn off the accumulated vegetation

In this scenario the entire residential site and large surrounding areas are assumed to be uniformly contaminated with plutonium and americium at the RSAL concentration values Residents are assumed to spend 175 to 350 days per year (average of 234 days), 24 hours per day, for 1 to 87 years (average of 13 years) The residents would live on five-acre sites with undeveloped surface soils and native vegetative cover over contaminated soils Cover from lawn grasses, which would reduce exposure, has not been used in this or any other scenario Homegrown produce would be ingested, but no shallow groundwater would be consumed as drinking water

Figure 3-2 provides a conceptual site model that delineates the potential pathways for exposure to contaminants by a resident

RURAL RESIDENT EXPOSURE SCENARIO



S = Significant Pathway
I = Insignificant Pathway
IC = Incomplete Pathway

(Only significant pathways will be quantitatively assessed)

Figure 3-2 Conceptual Site Model for Rural Resident scenario

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Exposure Pathways for Rural Resident Scenario

The exposure pathways associated with the Rural Resident scenario are ingestion of surface soil/indoor dust, ingestion of contaminated homegrown produce, inhalation of surface soil/indoor dust particles, and external exposure to gamma radiation These four pathways were determined by performing a pathway sensitivity analysis for a residential user and then applying the site conceptual model to remove any non-applicable pathways

Pathways that would not be complete or significant for the resident have been excluded The pathways of consumption of shallow groundwater, consumption of meat, milk, and aquatic food from the site, and exposure to radon, tritium, and carbon-14 (attributable to natural background only) were excluded because they are not believed to be viable contributors for this scenario

3.1 3 OPEN SPACE USER SCENARIO

The Open Space User scenario represents a future user of Rocky Flats who visits the site for occasional recreation This scenario is one of several potential uses identified in RFCA after cleanup is completed This scenario describes a site that remains as open space and would not be developed in the future The Open Space User scenario anticipates access by the public to the Buffer Zone in a manner similar to other open spaces currently used nearby in Jefferson and Boulder counties For example, the time an open space user spends on site in this scenario is consistent with recent survey data from these counties (Jefferson County, 1996, Boulder County, 1995)

In this scenario, both children and adults may visit the open space 100 times per year and spend 2 5 hours per visit, all outdoors In addition, they could visit the site over a period of 30 years No fruits, vegetables, or water originating from the site would be routinely ingested Native vegetative cover would be present over the entire open space area, except in the aftermath of a prairie fire Concentrations of windblown contaminated soil particles are assumed to increase significantly during some visits due to fires that would have occurred on contaminated parts of the open space All areas where visitors may be exposed on site would have contamination equal to the RSAL concentrations

Figure 3-3 provides a conceptual site model that delineates the potential pathways for exposure to contaminants by a visiting open space user

OPEN SPACE USER EXPOSURE SCENARIO

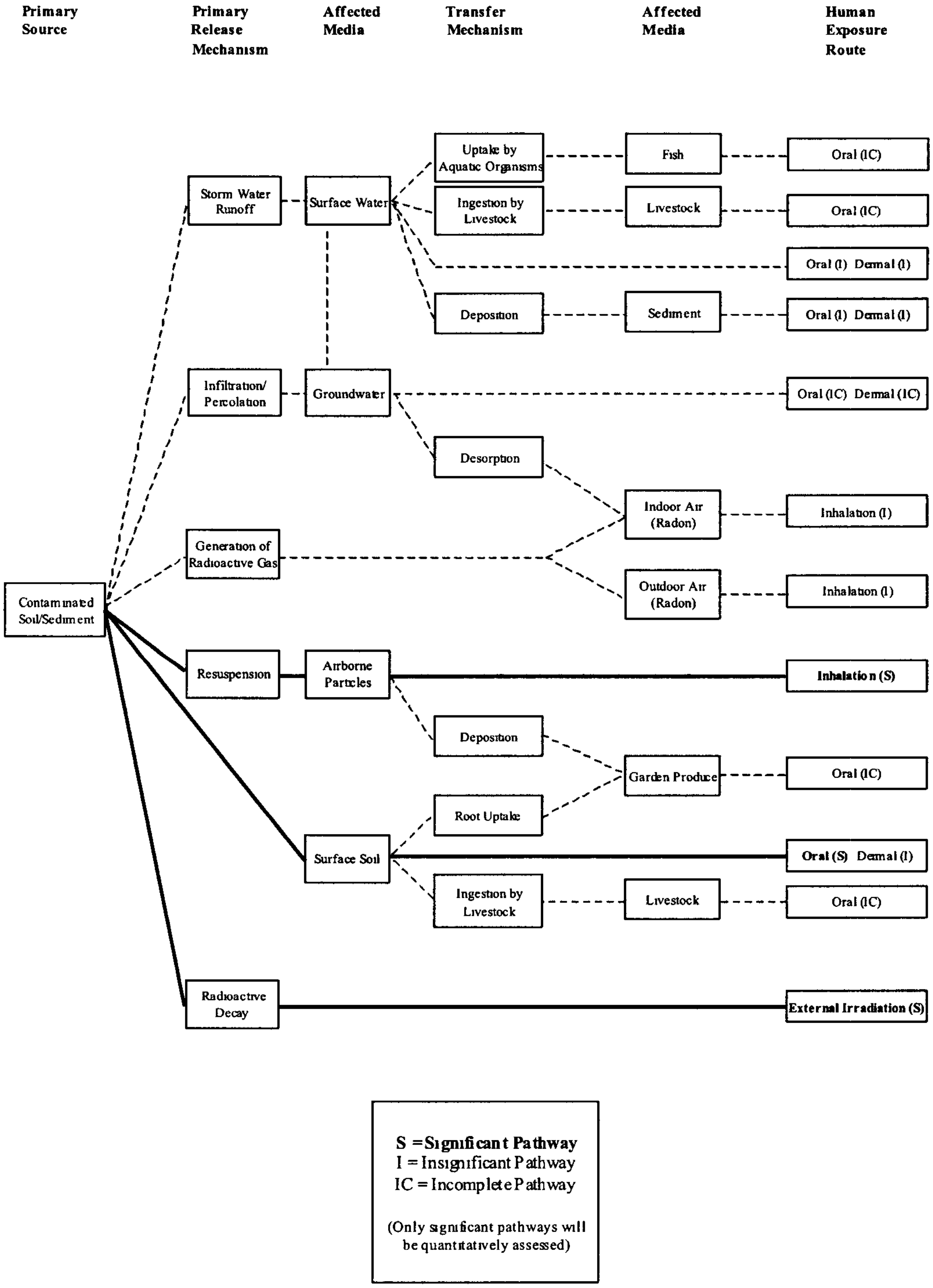

Figure 3-3 Conceptual Site Model for Open Space User scenario

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Exposure Pathways for Open Space User Scenario

Three exposure pathways are considered to be complete and potentially significant for the Open Space User scenario soil ingestion, dust inhalation, and external gamma exposure from contaminated surface soil These exposure pathways are quantitatively assessed in deriving an RSAL for the open space user

Pathways that would not be accessible to the user have been excluded For instance, the consumption of contaminated garden fruits and vegetables and the consumption of contaminated shallow groundwater as drinking water have been excluded for the Open Space User scenario because these pathways are not viable Pathways requiring consumption of meat, milk, or aquatic food grown on site, or those requiring exposure to radon, tritium, and carbon-14 (attributable only to natural background) have also been excluded

3.1.4 Office Worker Scenario

RFCA lists commercial/industrial development as a possible future use for Rocky Flats An Office Worker scenario was chosen to represent a potential future user after cleanup Office workers considered in this scenario are adult men and women working in an administrative environment, spending 100% of their time indoors Time on-site would be 8 hours per day, 5 days per week for 250 days or 2,000 hours per year Workers are assumed to spend 25 years working at the site Maintenance workers are grouped into the potentially exposed population characterized by the Wildlife Refuge Worker scenario, rather than the Office Worker scenario

The commercial/industrial development area where the offices would be located is the contaminated area, most of which is undeveloped surface soils with only native vegetative cover over contaminated soils Office workers would be exposed to soil indirectly via ingestion and inhalation of indoor dust assumed to infiltrate through the building's ventilation system Grass fires that burn off the vegetation would increase dust in the air occasionally The office workers would be partially shielded from gamma radiation from surface soils due to building structures Office workers would not consume fruits, vegetables, or shallow groundwater that originate at the site

Figure 3-4 provides a conceptual site model that delineates the various potential pathways for exposure to contaminants by an office worker

OFFICE WORKER EXPOSURE SCENARIO

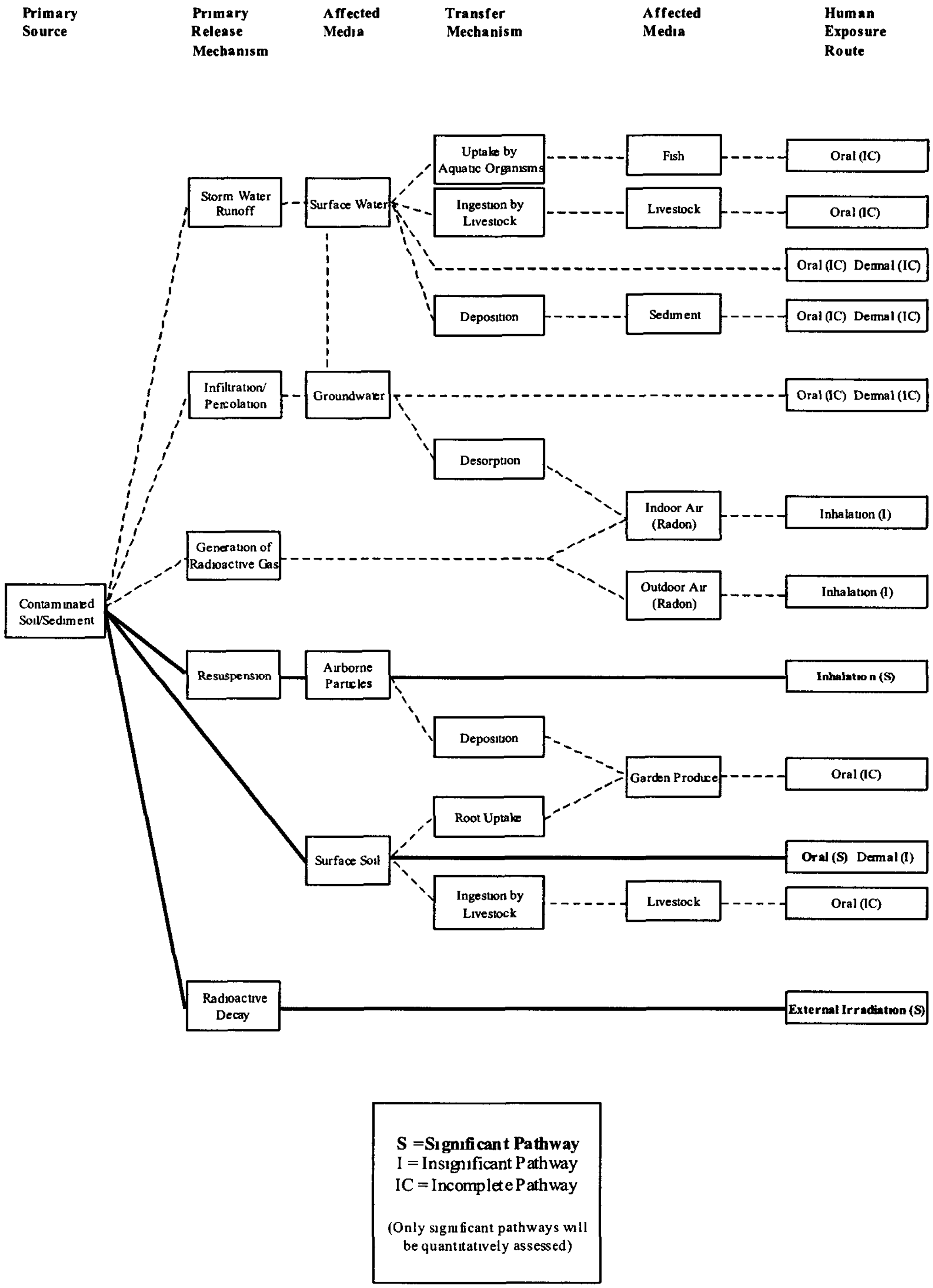

Figure 3-4 Conceptual Site Model for Office Worker scenario

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Exposure Pathways for Office Worker Scenario

The exposure pathways associated with the Office Worker scenario are incidental ingestion of surface soil/indoor dust, inhalation of surface soil/indoor dust particles, and external exposure to gamma radiation A sensitivity analysis was conducted on each of these pathways as well as on the combination of all three pathways to identify the input variables that are most influential in the dose calculations for office workers using RESRAD

The consumption of contaminated garden fruits and vegetables and the consumption of contaminated shallow groundwater as drinking water were excluded for the Office Worker scenario because these pathways do not exist for an office worker In addition, the pathways requiring consumption of meat, milk, and aquatic food grown on site, and exposure to radon, tritium, and carbon-14 (attributable to natural background only) were excluded because they are not applicable to the scenario

3.2 EXPOSURE PATHWAYS WITH INSIGNIFICANT CONTRIBUTIONS TO DOSE OR RISK

A number of potential pathway analyses have been excluded for this RSAL analysis These pathways are excluded either because the pathway is not linked physically between the source and the potential receptor, or because the potential dose from the pathway is insignificant compared to the primary pathways This section describes the rationale for excluding certain pathways as contributors to dose or risk for future exposed individuals at Rocky Flats

Direct Contact Dermal Absorption Pathway

In risk analysis, transfer of contaminants to a receptor through contact with the skin is a potential pathway associated with surface soil, sediments, or contaminated water Dermal contact is considered to be a complete but insignificant pathway Although some receptors will have direct contact with the soil and water, plutonium, americium, and uranium will not be absorbed through intact skin In all scenarios, drinking water and irrigation water, if used, would be provided from reliable deep wells or from commercial water systems Direct contact with surface water would only be incidental in any of the scenarios

Inhalation of Gases

The presence of gaseous radionuclides, primarily isotopes of radon and its daughter products, provides a potential exposure route to humans At Rocky Flats, the primary sources of radon are naturally occurring radionuclides in soil (natural background radioactivity) Although isotopes of radon are ultimately produced in the decay chains of americium, plutonium, and uranium, the contaminants attributable to Rocky Flats operations were introduced into the environment as relatively pure substances, that is, without significant decay products present In such cases, the time required to decay to radon isotopes is extremely long, i e , hundreds of thousands to billions

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of years Because of the long time required, the working group considers that the exposure pathway for radioactive gases attributable to the americium, plutonium, and uranium from Rocky Flats is incomplete As such, inhalation of gases is not included as an exposure pathway in this assessment

Ingestion of Surface Water, Groundwater, and Food

Candidate exposure routes to humans from surface water related contaminant sources include the potential ingestion of surface water Ingestion of surface water is considered a complete pathway since individuals who visit or inhabit the site could splash water into their mouths or drink the raw water during a visit or sojourn across Rocky Flats The availability of water is limited and the incidence of raw surface water ingestion by any of the users defined in these scenarios would be rare, resulting in an insignificant pathway Surface water flow rates in the streams affected by surface contamination are expected to vary such that both the quality and quantity would be insufficient as a source for drinking or other domestic purposes

Potential contaminant exposure routes for groundwater include oral ingestion of lower or upper groundwater layers Groundwater contribution to dose and risk is considered part of an incomplete pathway The only exposed individual who would potentially use shallow groundwater, as a drinking source would be the rural resident This scenario does not assume a subsistence existence, but assumes instead a rural resident who lives on a five-acre plot and uses potable water derived either from a deep well or from a domestic water system

A recent white paper (RMRS, 2001) concluded that it might be possible for wells at Rocky Flats to provide sufficient quantities of water to serve as a primary source of drinking water However, the study was limited to looking only at the potential yields of wells that were unaffected by any other withdrawal of water from that same shallow source, and included imported water now leaking into and potentially contributing to the shallow water table The working group concluded that such wells could not provide enough water for domestic use on a sustained basis The potentially contaminated shallow groundwater supply would not be sufficiently reliable to be used routinely nor would such use be legally acceptable practice In none of the scenarios defined would the exposed individuals be expected to have access to or use groundwater Neither the surface water nor groundwater pathways are quantitatively assessed in the four scenarios

The ingestion of contaminated fish, meat, and dairy products is an incomplete pathway in all scenarios and will not be quantitatively assessed Fish living on site in the ephemeral streams are too small to be fished or eaten Livestock grazing would not be viable on the small plots allocated for the rural resident, except when fed large quantities of purchased grains and hay grown elsewhere The uptake of contaminants by livestock through limited incidental grazing is not likely to be a significant contributor to potential dose These pathways are considered incomplete and will not be quantitatively assessed

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3.3 SOLUBILITY OF PLUTONIUM AND AMERICIUM

Plutonium and Americium in Water

The mobility of environmental plutonium and americium in water is severely limited due to the extremely low solubility of these materials At Rocky Flats, the plutonium is commonly identified as weapons-grade plutonium Americium in this environment is associated with the same material, as a result of in-growth (decay) from Pu-241 to Am-241 The RESRAD groundwater transport calculations treat plutonium and americium separately, and need to be performed with care to adequately represent the behavior of weapons-grade material containing both If the distribution coefficients for the two materials are treated as though they are pure materials, the contribution of americium from a weapons-grade mix will be overestimated

Actinide migration evaluation (AME) at Rocky Flats have shown that the plutonium found in surface water is transported not as dissolved molecules but as particles of plutonium oxide attached to colloids of organic material smaller than a 0 45 micron pore-size filter (Kaiser-Hill Inc , LLC, 2002) Typically, elevated concentrations of plutonium that have been observed in surface water runoff are not observed downstream of the detention ponds at the site The detention ponds are very effective in reducing the concentration of plutonium, due to settling of the particulate material into the pond sediments

4.0 SELECTION OF INPUT PARAMETERS FOR DOSE AND RISK CALCULATIONS

Potential RSALs were calculated based on both effective dose (hereafter, "dose"), an estimate of damage to the body from ionizing radiation, and risk, the likelihood of getting cancer (and non-cancer from uranium) due to the modeled exposure scenario The dose-based calculations were performed using the equations and variables in the RESRAD computer model (version 6 0), and the risk-based calculations were performed using EPA's Standard Risk Assessment Methodology (U S EPA, 1989, 1991, 2001b) The spreadsheet calculations used to implement the *Risk Assessment Guidance for Superfund (RAGS)* will be referred to as the Standard Risk equations in this assessment report Risk methods use mathematical formulas to estimate the average daily amount of contaminant that a hypothetical individual is exposed to, whereas dose methods estimate annual exposure With the dose assessment method, the amount of exposure is multiplied by a dose conversion factor to determine a predicted dose With the risk assessment method, the amount of exposure is multiplied by a cancer slope factor to yield a risk estimate Appendix D describes the RESRAD model and parameter values for each exposure variable Appendix B describes the equations and variables used in the risk-based approach for each land use scenario (e g , Residential, Wildlife Refuge Worker) and for each exposure pathway (e g , soil ingestion, inhalation) A summary of the point estimates and probability distributions for each exposure variable in the risk approach is presented in Chapter 4 An example of a risk-based RSAL equation for soil ingestion is shown in Equation 1-1 below

$$RSAL = \frac{TCR}{SF_{oral} \times SIR \times EF \times ED \times CF} \qquad \text{Equation 1-1}$$

where,

RSAL	=	Radionuclide Soil Action Level (pCi/g)
TCR	=	Target Cancer Risk (unitless)
SF_{oral}	=	Oral Slope Factor (risk/pCi)
SIR	=	Soil Ingestion Rate (mg/day)
EF	=	Exposure Frequency (day/yr)
ED	=	Exposure Duration (years)
CF	=	Conversion Factor (0 001 g/mg)

The equation consists of three exposure variables (soil ingestion rate, exposure frequency, and exposure duration), a toxicity variable (SF_{oral}), and a TCR, such as 10^{-5} These variables can be described by either single values or by a range or distribution of values For example, the number of years an individual may reside on a contaminated site can be described as 30 years or as a range from 1 to 87 years Target cancer risk is a risk level of concern typically based on site-specific information

If the RSAL is calculated using only single values or point estimates to represent each variable, the calculation is referred to as a point estimate approach (also called deterministic approach) The output or RSAL value from this approach will be a single value If one or more of the variables in the equation are represented by a distribution of values, otherwise known as probability distributions, the calculation is referred to as a probabilistic approach When one or more of the equation inputs are probability distributions, the output will be a distribution of

RSALs While this example focuses on a risk-based calculation of an RSAL, the same concepts apply to the dose-based calculation of RSALs The distribution of RSALs provides information on the variability in potential soil action levels, each of which yields a specified risk level of concern Figure 4-1 illustrates the conceptual approach to a probabilistic model that uses Monte Carlo simulation to characterize inter-individual variability in exposure A series of input variables are described by probability distributions, which are combined in a mathematical function for calculating an RSAL, resulting in a distribution of RSALs

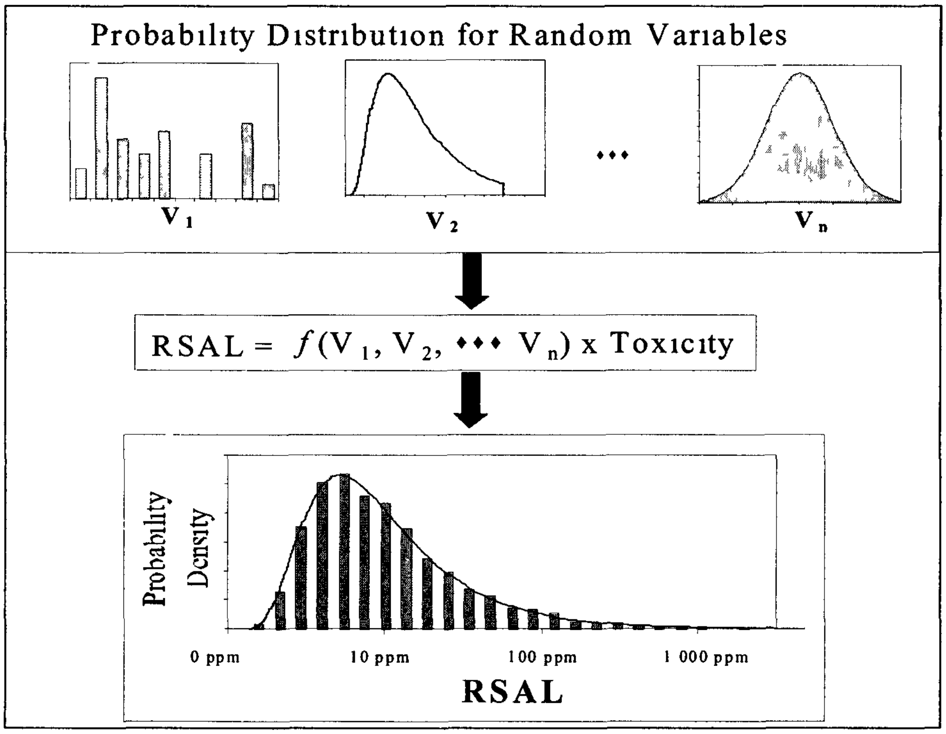

Figure 4-1 Conceptual model Monte Carlo analysis Random variables (V_1, V_2, V_n) refer to exposure variables (e g , body weight, exposure frequency, ingestion rate) that are characterized by probability distributions A unique, risk-based radionuclide soil action level (RSAL) estimate is calculated for each set of random values Repeatedly sampling (V_i) results in a frequency distribution of RSALs, which can be described by a probability distribution and summary statistics

In addition to calculating RSALs, the exposure variables for each pathway were assessed in terms of their relative contributions to the RSAL In general, the results of sensitivity analysis can guide decisions to use either a probability distribution or a point estimate to characterize variability in exposure The EPA policy recommends against developing site-specific probability distributions for human health toxicity values at this time, so point estimates were used for dose conversion factors and cancer slope factors (U S EPA, 2001b) These toxicity values are discussed in detail in Sections 4-7 and 4-8

4.1 PROCESS FOR DEFINING PARAMETER VALUES FOR EXPOSURE VARIABLES

After inspection of the conceptual site models in this assessment (see Chapter 3), it is immediately apparent that there are a large number of exposure scenarios, exposure pathways, and input variables that must be evaluated at the Rocky Flats site Selecting and fitting probability distributions for all of these variables can be time and resource intensive, and is generally unnecessary Therefore, it is important to identify factors that have a strong influence on the outcome early in the process For example, the Rural Resident and Wildlife Refuge Worker scenarios were considered to be the scenarios with the greatest influence on risk decisions at Rocky Flats For that reason, the working group focused their efforts on developing the probabilistic assessment for these two scenarios The Office Worker and Open Space User scenarios were represented by point estimate assessments only

For identifying which pathways and variables most strongly influence the RSAL estimate, sensitivity analyses are invaluable These analyses provide quantitative and qualitative information that allows the modeler to focus on the variables that are most important to the outcome of the dose or risk assessment

This section describes in detail the process used to conduct the sensitivity analysis The intent is to identify the most influential exposure pathway(s) and then to identify and quantitatively rank the most influential variables within each pathway The results of those sensitivity analyses are shown in this and following sections

For those variables identified as most influential, the RSAL working group evaluated the existing data to determine if a probability distribution could be developed If the data were deemed adequate, a distribution was developed If they were not, a health protective point estimate was selected The inputs selected for each of the influential variables are described in detail in Appendix A It is important to note that when a sensitivity analysis is performed and the major variables are identified, this does not mean that the less influential pathways and variables are eliminated from a risk assessment They are kept in the assessment, typically as point estimates For those variables that were not identified as being especially influential, the default point estimates in RESRAD 6 0 or the default point estimate recommended by EPA (U S EPA, 1991), were used For the most part, these were consistent with the point estimates used in the 1996 Rocky Flats programmatic preliminary remediation goals spreadsheets and their updates These variables are presented in Appendix C for risk calculations and Appendix D for dose calculations These combinations of probability distributions and point estimates were used to calculate the probabilistic RSALs

4 1 1 SENSITIVITY ANALYSIS

The effort to understand the origin, quality, and representativeness of the data available to specify each input variable in a highly parameterized model can be quite resource intensive In general, a greater level of effort should be directed towards input variables that have the greatest influence on the model output The working group applied a sensitivity analysis to identify and quantitatively rank the influence of each input variable on the model's output For the point estimate calculations of RSALs, a systematic approach was used to evaluate how the output of

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RESRAD 6 0 varies in response to changes in baseline parameter values Results of initial sensitivity analyses were used in this assessment to direct resources towards the subset of exposure pathways and variables that caused the greatest response in the model's output, in this case, the predicted dose A similar approach was applied to the risk-based calculations of RSALs using the Standard Risk equations For the probabilistic calculations, sensitivity analysis was used to highlight the exposure variables that contribute most to the variability in the model output

4.1 2 SENSITIVITY ANALYSIS PROCESS

Dose Calculation Sensitivity Analyses

This section describes the sensitivity analysis process used in RESRAD 6 0 RESRAD 6 0 provides a sensitivity analysis module to assist the user who wants to perform such an analysis The sensitivity analysis is bracketed around an initial input parameter value for each variable The initial input parameters, or baseline values, were selected from values used in the 1996 RSAL analysis, except in cases where new information or new model requirements drove changes Baseline values were reviewed prior to performing the analysis to ensure the baseline value and the resulting range of variability on that value was physically plausible and were compatible with the computational capabilities of the models Using the module, input parameters can be varied to provide inputs ranging from some fixed fraction of the baseline parameter value to an equal multiple of the same baseline For example, a parameter can be varied from one-third baseline to three-times baseline, or from one-tenth to 10 times, etc For these extremes, the model is exercised keeping all other exposure variables fixed at baseline parameter values, and the resultant doses are recorded The relative change in dose can then be compared to the relative change in input value This point estimate sensitivity analysis method of comparing the relative change in output to a relative change in input is sometimes referred to as an elasticity equation

The working group performed the RESRAD sensitivity analyses separately for each pathway that would be active in the Rural Resident scenario, by varying a subset of exposure variables that are relevant to a specified exposure pathway The analysis was also conducted on the combination of all active pathways, so that the net influence of all variables across all pathways could be assessed The Rural Resident scenario was used for this analysis since it contains the most comprehensive set of active exposure pathways, and is the scenario that is likely to provide the lowest RSALs The relevant exposure pathways considered in the sensitivity analysis for the Rural Resident scenario are listed in Table 4-1

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Table 4-1 Active and suppressed exposure pathways for Rural Resident scenario in RESRAD sensitivity analysis

RESRAD 6 0 Exposure Pathways	Active	Suppressed
External gamma	X	
Inhalation	X	
Plant ingestion	X	
Meat ingestion		X
Milk ingestion		X
Aquatic foods		X
Drinking water		X
Soil ingestion	X	
Radon		X

Since the results of the sensitivity analysis may depend on the relative amount that each input is varied, the working group chose to vary each baseline value by a factor of 10 For input variables with a plausible minimum or maximum value (e g , minimum soil ingestion rate of 0 g/yr), the change in the baseline value was confined to the plausible range Baseline values were selected from a variety of sources including RESRAD defaults and 1996 parameter values and were adjusted on occasion to ensure the physical range of interest was encompassed by a factor of three Certain parameters were adjusted at later dates based on scientific or site-specific information In some cases, the current values lie outside the range tested

Table 4-2 lists the starting or "baseline" values and plausible ranges used for each exposure variable in the RESRAD simulation The baseline values may differ from the actual point estimates used in the risk assessment (see Appendix D) The values were selected to facilitate the calculations of sensitivity coefficients using a variety of methods

Risk Calculation Sensitivity Analysis

A sensitivity analysis was also performed using EPA Standard Risk equations In addition to the sensitivity ratio method described above, correlation analysis was used to identify the most influential exposure pathways and variables from the probabilistic (Monte Carlo) simulations Using Crystal Ball® (Decisioneering, Inc , 2001), a set of probability distributions was defined for input variables, a Monte Carlo simulation was run with 10,000 iterations to generate a distribution of RSALs at a specified risk level, and Spearman Rank correlations were calculated to determine the relationship between each input variable and the model output An example of the results of the probabilistic analysis for americium for the Rural Resident scenario is given by the tornado plots in Figures 4-2 and 4-3 These figures provide two different approaches to summarizing the same statistical analysis—Figure 4-2 shows the contribution to variance in the output distribution by calculating the square of the correlation coefficient for each variable and normalizing the sum of squares to 100% Figure 4-3 shows the Spearman rank correlation

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coefficient For this analysis of americium, the exposure duration is the dominant exposure variable with 94 4% contribution to variance and a rank correlation of 0 94 The second most influential variable is the childhood soil ingestion rate, with only 1 0% contribution to variance and a rank correlation of 0 10 Appendix H gives the complete set of tornado plots for americium and plutonium for the Rural Resident and Wildlife Refuge Worker scenarios

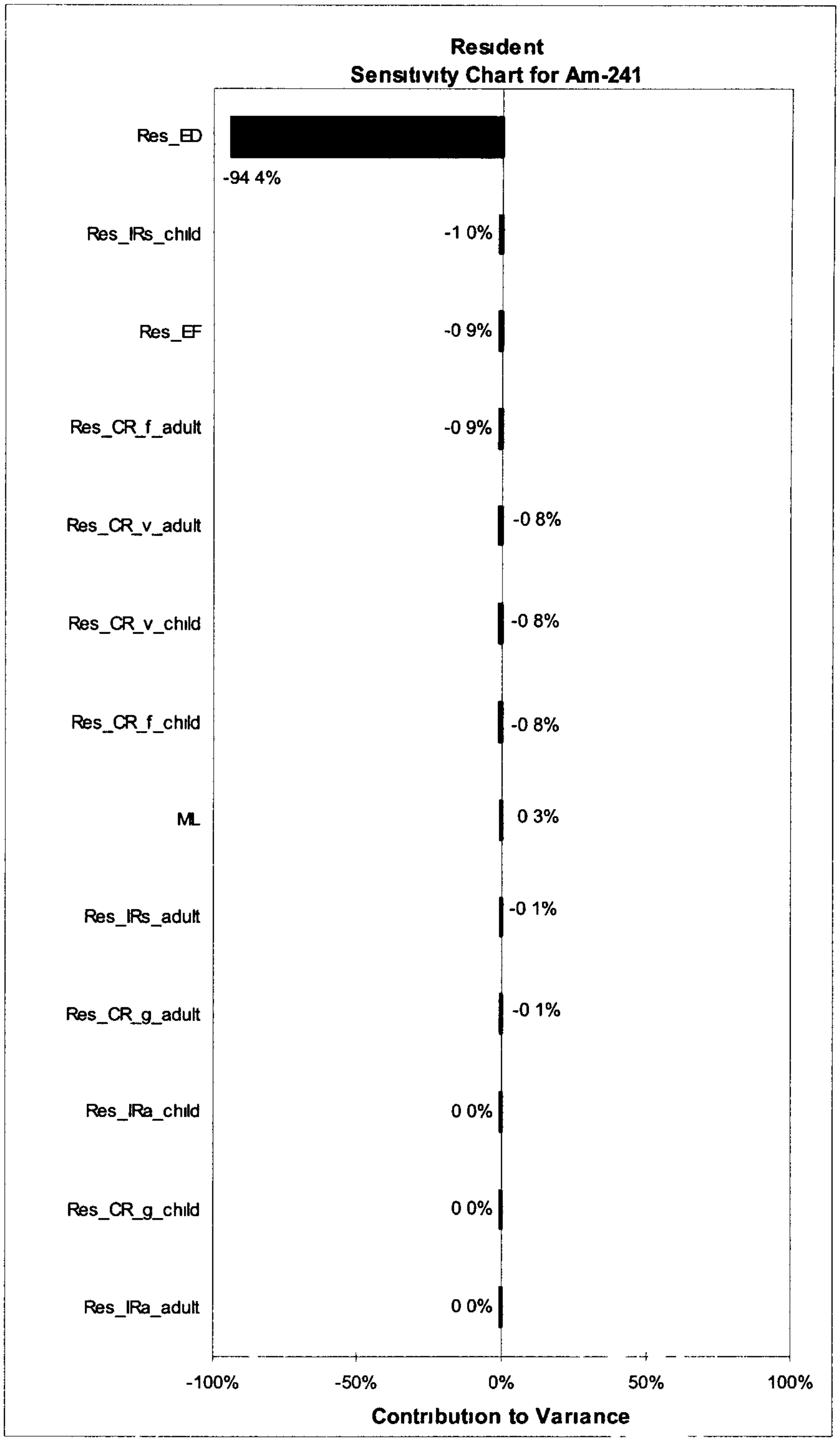

Figure 4-2 Example of probabilistic sensitivity analysis result for americium, Rural Resident scenario, using Standard Risk equations – *contribution to variance* in RSAL

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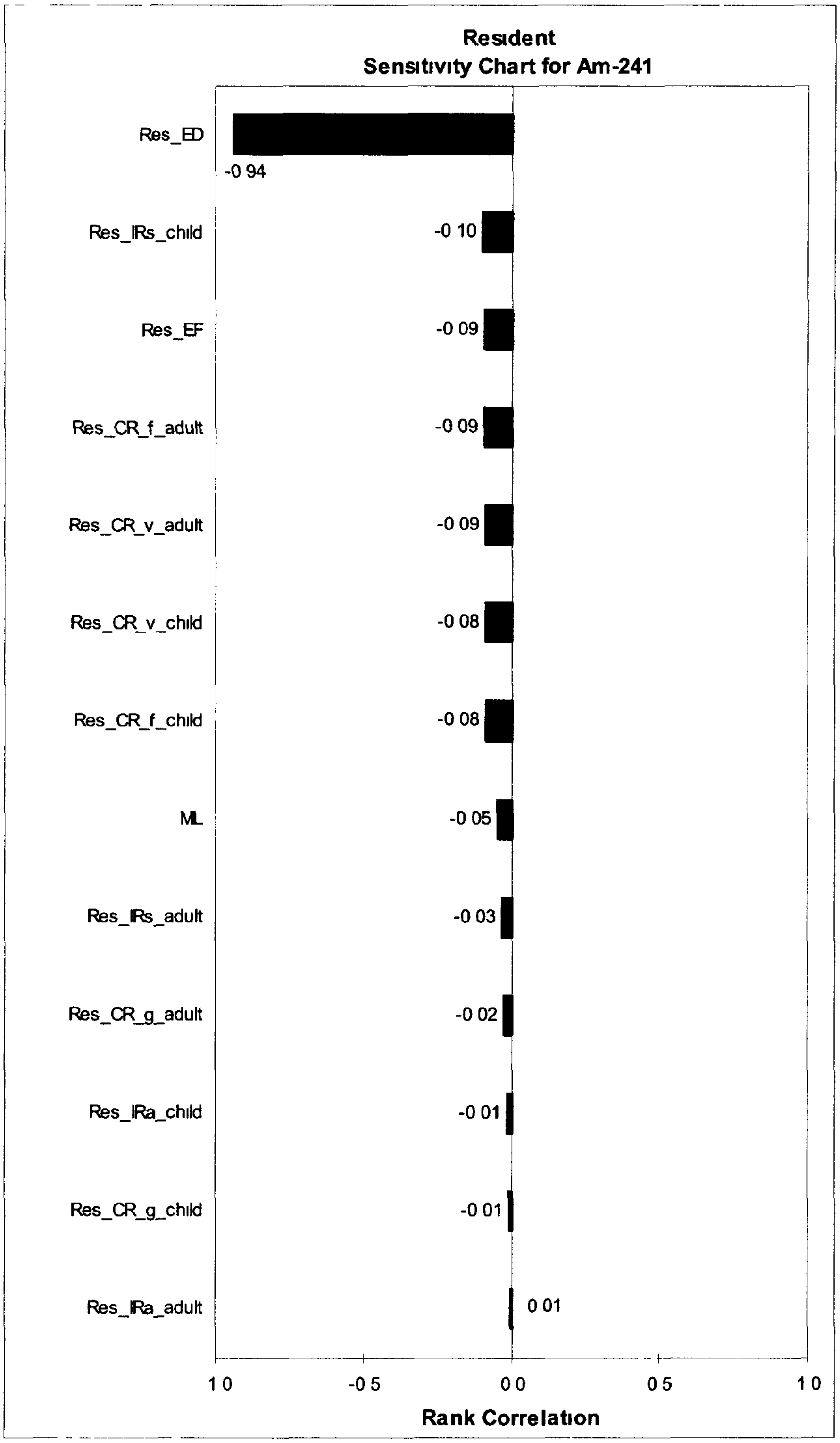

Figure 4-3 Example of probabilistic sensitivity analysis result for americium, Rural Resident scenario, using Standard Risk equations – *rank correlation* with RSAL

Table 4-2 Baseline values and plausible ranges (minimum, maximum) for the point estimate sensitivity analysis using RESRAD 6 0 [1]

RESRAD 6 0 Input Variables	RESRAD 6 0 Default	Sensitivity Baseline Value	Range for Sensitivity Analysis		Value Used
			Minimum	Maximum	
Contaminated Zone Variables					
Area of contaminated zone (m^2)	10,000	5,000	100	250,000	1,400,000
Thickness of contaminated zone (m)	2 0	0 05	0 01	0 25	0 15
Occupancy, Inhalation, and External Gamma Data					
Inhalation rate (m^3/yr)	8,400	7,000	2,448	19,950	distribution
Mass loading for inhalation (μg/m^3)	0 0001	0 00005	0 00001	0 00025	distribution
Indoor dust inhalation shielding factor (unitless)	0 4	0 8	0 6	1 0	0 7
External gamma shielding factor (unitless)	0 7	0 8	0 6	1 0	0 4
Indoor time fraction (unitless)	0 5	0 68	0 49	0 95	distribution
Outdoor time fraction (unitless)	0 25	0 07	0 02	0 25	distribution
Cover and Contaminated Zone Hydrological Data					
Density of contaminated zone (g/cc)	1 5	1 6	1 1	2 4	1 8
Average annual wind speed (m/s)	2 0	4 25	3 04	5 95	4 2
Precipitation (m/yr)	1 0	0 381	0 191	0 762	0 381
Ingestion Pathway, Dietary Data					
Fruit, vegetable, and grain consumption (kg/yr)	160	40 1	13 4	120 3	distribution
Leafy vegetable consumption (kg/yr)	14	2 6	0 9	7 8	distribution
Soil ingestion (g/yr)	36 5	50	25	100	36 5
Contaminated fraction, plant food (unitless)	-1 0	0 5	0 25	1 0	1 0
Ingestion Pathway, Nondietary Data					
Mass loading for foliar deposition (g/m^3)	0 0001	0 00005	0 00001	0 00025	distribution
Depth of soil mixing layer (m)	0 15	0 05	0 01	0 25	0 15
Depth of roots (m)	0 9	0 2	0 05	0 8	0 15

[1] The extremes of many of the probability distributions may be found to lie outside the sensitivity ranges tested, but the results of the sensitivity analysis are still valid when the majority of the distribution lies inside the range This conclusion results from the realization that the parameter responses are well characterized in the models, and have relatively simple interactions with other parameters

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4.1.3 SENSITIVITY ANALYSIS INTERPRETATION

Interpretation of the sensitivity analysis requires either a quantitative or a systematic qualitative ranking method to deal with the sensitivity outputs from RESRAD or Standard Risk Assessment Methodologies The inputs and outputs were combined in a manner that first normalized the changes in input and output against baseline values so that a direct comparison of the relative changes would be possible The necessity of this step can be made clear by considering that some inputs may have varied by amounts as small as 0 0004 units of measure, while others may have varied by 4,900 units, yet the relative change is the same, say a factor of three Without normalization to the baseline parameter values, their relative effects on dose could be lost to their disparity in magnitude

Normalized responses have been calculated using three different algorithms, two are based on changes relative to the baseline, and the third is based on the range between the extremes of the dose calculation corresponding to minimum and maximum of the input range The normalized responses are expressed as "sensitivity coefficients", which are unitless quantities Table 4-3 gives the equations for the three approaches used to calculate sensitivity coefficients in this assessment

Table 4-3 Three equations for calculating a sensitivity coefficient

Deviation from Baseline	Equation for Calculating Sensitivity Coefficient (S)[1]
Minimum	$S_{base\ min} = (D_{base} - D_{min})/D_{base} \ / \ (P_{base} - P_{min})/P_{base}$
Maximum	$S_{base\ max} = (D_{max} - D_{base})/D_{base} \ / \ (P_{max} - P_{base})/P_{base}$
Range	$S_{max\ min} = (D_{max} - D_{min})/D_{base} \ / \ (P_{max} - P_{min})/P_{base}$

[1]S = sensitivity coefficient, D = dose, P = parameter, base = baseline value

Negative values for sensitivity coefficients may occur if there is an inverse relationship between an RSAL and an input value (i e , lower values for an input variable yield higher values for an RSAL) By calculating the absolute value for each coefficient, the results can be expressed as positive numbers and then rank ordered Input variables with the highest (absolute value) coefficients can be easily identified for further analysis Tornado diagrams in Figures 4-4 and 4-5 for inhalation and soil ingestion pathways, respectively, give results for the dose-based calculations using RESRAD Similar diagrams resulted for all the pathways examined Figure 4-6 gives the results for the three sensitivity-coefficient approaches applied to dose calculations that combine all exposure pathways

The most sensitive variables for a scenario are those variables within a given pathway that will have the greatest influence or impact on the RESRAD (or Standard Risk Assessment Methodologies) model outputs Figures 4-4 and 4-5 show the ranked sensitivity coefficients representing $S_{max-min}$ As can be noted, only the first several coefficients (from the bottom) have

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values approaching one, that is, display changes in dose that is similar in relative magnitude to the change in parameter Another less sensitive group displays a measurable change but notably smaller than that displayed by the first group, the remainder (including those not shown) display even smaller responses, suggesting that relatively large uncertainty in their selection would be inconsequential to the final result Parameter values for the more sensitive variables, however, need to be selected with great care if the final result is to represent the true consequences associated with exposure in the land use scenario that is being investigated The other sensitivity calculations, $S_{base\text{-}min}$ and $S_{base\text{-}max}$ did not prove as useful for assessing sensitivity itself, but provided insight into the mechanisms that might be causing a variable to display a certain response These observations are discussed in the next section

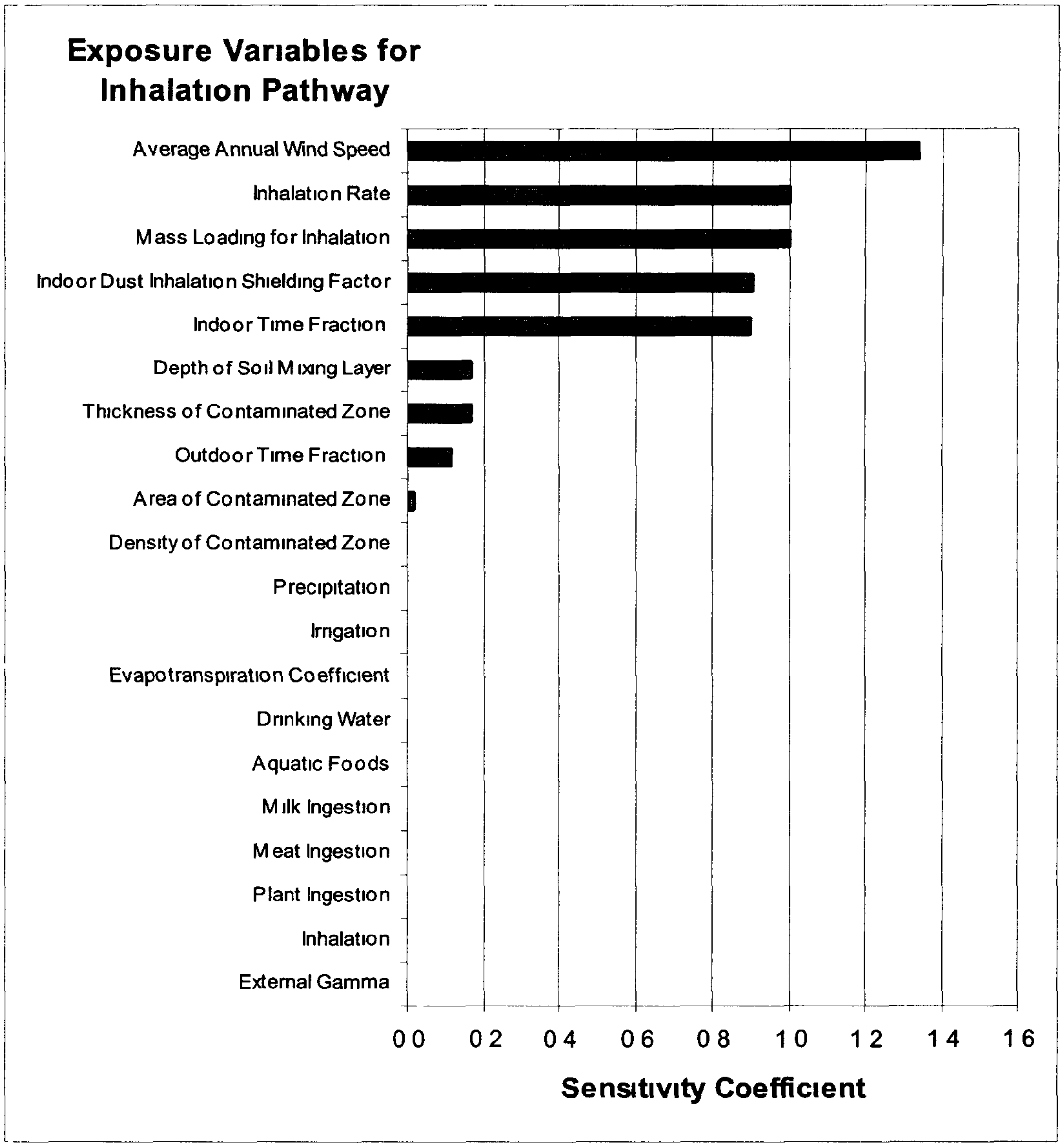

Figure 4-4 Ranking of top 20 input variables based on point estimate sensitivity coefficients calculated with RESRAD by comparing the baseline value to the plausible range (max–min) Results are for plutonium, Rural Resident scenario, and *inhalation* exposure pathway only

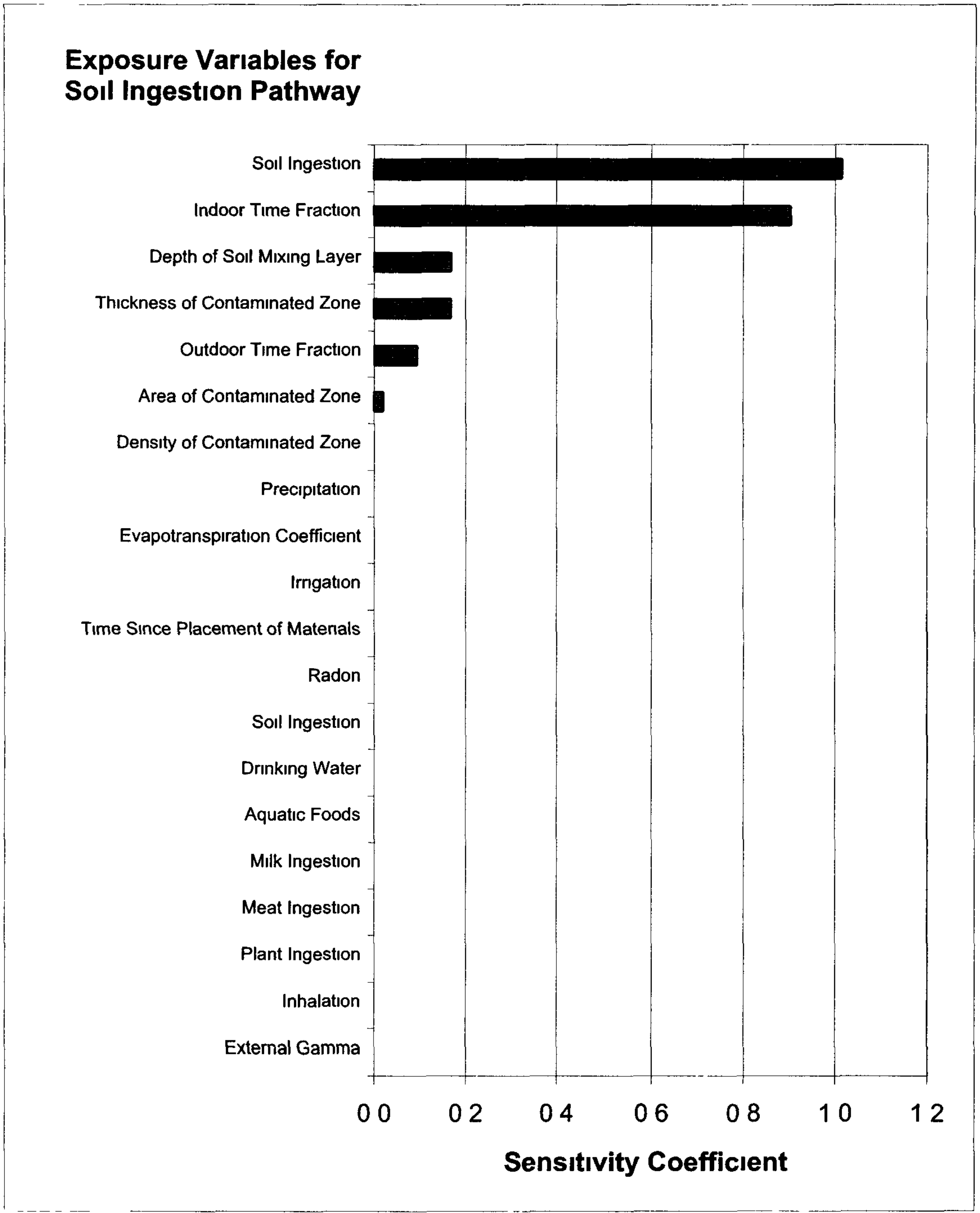

Figure 4-5 Ranking of top 20 input variables based on point estimate sensitivity coefficients calculated with RESRAD by comparing the baseline value to the plausible range (max–min) Results are for plutonium, Rural Resident scenario, and *soil ingestion* exposure pathway only

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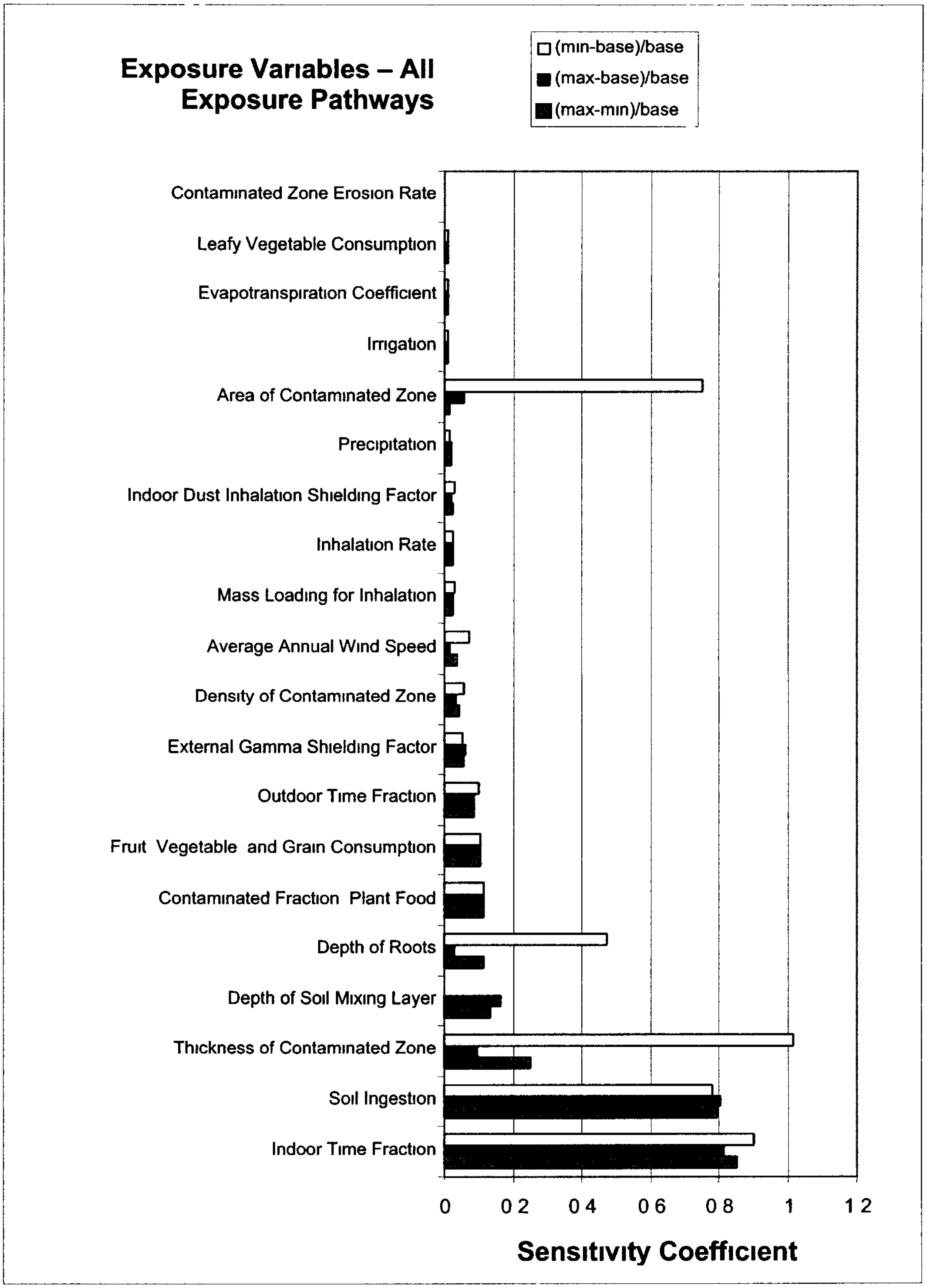

Figure 4-6 Ranking of top 20 input variables based on point estimate sensitivity coefficients calculated with RESRAD using all three methods in Table 4-3 Results are for plutonium, Rural Resident scenario, and *all* exposure pathways combined

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Highly Sensitive and Moderately Sensitive Input Variables Based on Sensitivity Coefficients

The most sensitive exposure variables, determined from the combined analysis of all pathways for weapons-grade plutonium, are easily identified in Figure 4-6 Table 4-4 lists the most sensitive and moderately sensitive input variables The working group added “mass loading for inhalation” to this most sensitive list, to some extent because of the great interest in the post-fire scenarios following the RAC independent assessment of the 1996 RSALs, but also because mass loading under a fire scenario is described by a discrete probability distribution This latter parameter behavior could not be tested using the sensitivity analysis protocols as implemented in the RESRAD code The remainder of the input variables had relatively low sensitivity coefficients and are not listed in Table 4-4

Table 4-4 Results of point estimate sensitivity analysis with RESRAD 6 0

Most Sensitive Input Variables	Moderately Sensitive Input Variables
Indoor Time Fraction	Thickness of the Contaminated Zone
Soil Ingestion Rate	Depth of Soil Mixing Layer
Mass Loading for Inhalation	Depth of Roots
	Contaminated Fraction, Plant Food
	Fruit, Vegetable, and Grain Consumption Rate
	Outdoor Time Fraction
	External Gamma Shielding Factor
	Density of Contaminated Zone
	Average Annual Wind Speed
	Soil-to-Plant Transfer Factor
	Inhalation Rate
	Indoor Dust Inhalation Shielding Factor

4 1 4 EXPOSURE DURATION IN RESRAD AND STANDARD RISK EQUATIONS

A sensitivity analysis was also run using EPA’s Standard Risk equations The grouping of input variables by relative magnitudes of sensitivity coefficients was consistent with the RESRAD results, with the exception of the exposure duration variable (as shown in Figure 4-2 and Figure 4-3) The RESRAD model does not specify exposure duration because the dose calculation is expressed as an average annual value However, a different time averaging approach is used in the Standard Risk equations Exposure duration plays a prominent role because exposure is expressed as an average daily dose over a long-time period (i e , multiple years) Furthermore, exposure duration is the most sensitive input variable in the sensitivity analysis using the Standard Risk equations As a result, exposure duration was included in the list of variables to be evaluated further in the probabilistic risk assessment approaches

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4.2 EXPOSURE PATHWAY SENSITIVITY

When all potential exposure pathways are active (i e , turned on) at the same time, the total dose is equal to the sum of the doses from each exposure pathway For the Rural Resident scenario, the soil ingestion pathway has a greater contribution to total dose than the other pathways (e g , inhalation, external irradiation, etc) As a result, the only variables that appeared as significant were in the soil ingestion pathway The working group felt that this approach may overshadow important variables within the other pathways Therefore, the working group decided to perform the sensitivity analysis on each pathway separately to identify the most significant exposure variables within each complete and potentially significant exposure pathway

Given similar exposures among multiple exposure pathways, the dose conversion factor is likely to have the greatest influence on the relative contribution of each pathway to total dose The dose conversion factor is used to convert the exposure (combination of internal exposure due to ingestion and inhalation of radionuclides and external irradiation) into a dose (the measure of potential health effect) Dose conversion factors are changed (vary) when more becomes known about the mechanisms that cause health effects from exposure to radiation, or when more becomes known about the mechanisms that cause the material to be introduced into the body For the analyses done here, the dose conversion factors from the most recently published values in International Commission on Radiation Protection (ICRP) Publication 72 (ICRP, 1996) were selected The use of dose conversion factors contained in ICRP 72 results in a higher dose attributable to the ingestion pathways for plutonium and americium than had been previously seen, and a reduced dose from the inhalation pathway The reasons for this difference are explained in detail below (Section 4 8)

If the sensitivity analyses were to be repeated using selection of dose conversion factors previously published in ICRP 30 (ICRP, 1979), the results would be somewhat different, favoring variables in the inhalation pathway more than is seen in the analysis presented here However, the working group has examined the relative changes in these variables and has concluded that the variables that would be identified as most influential to the results would not have changed

4.3 EXPOSURE VARIABLE SENSITIVITY

The working group focused on the sensitive and moderately sensitive input variables in an attempt to provide the most realistic and complete information possible Both adult and child populations have been considered where appropriate The working group did review and discuss the selection of the less sensitive variables, but only to the extent necessary to ensure completeness in the analytical process

As mentioned above, some variables displayed much more sensitivity than others The working group sought to understand this behavior before final selection of input values so that anomalous results could be identified, if present Again a graphical presentation of the sensitivity coefficients proved useful for identifying possibly anomalous results Figure 4-6 displays a combined output of all three sensitivity coefficients Differences between the three methods can be identified more readily with this graphic Such a result may be indicative of unexpected non-linear behavior or behavior that suggests the variable is a factor in multiple exposure pathways Results for selected input variables are discussed in the next section

4.3.1 Sensitivity of Selected Input Variables

Sensitive variables are described individually below Relationships between variables are highlighted, even though two variables may not have similar sensitivities and consequently do not appear in the same order in Figure 4-6

Indoor Time Fraction – The indoor time fraction has an important role in several of the exposure calculations, primarily by reducing exposure to external irradiation and outdoor dust

Outdoor Time Fraction – Outdoor time fraction does not display the same high sensitivity as the indoor time fraction The outdoor time fraction is a linear factor in all of the pathways

Soil Ingestion – Soil ingestion rate is a very important variable for the dose and risk estimates in all scenarios Dose and risk are linearly related to soil ingestion rate

Thickness of Contaminated Zone – The thickness of the contaminated zone has some influence on external exposure to gamma radiation, but its greatest influence is coupled with the influence of the "depth of roots" variable When the contaminated zone is very thin, and the roots extend significantly into uncontaminated soil, the dose and risk contribution from root uptake is dramatically reduced, conversely, when the contaminated zone is very thick, the roots are totally exposed to contamination and have the greatest uptake Combined together, this sensitivity response can be non-linear as is displayed in the graphic

Depth of Roots – Parallel discussion to "thickness of contaminated zone" discussion, above The working group chose to make the depth of roots equal to the thickness of the contaminated zone, thus maximizing the potential uptake by roots

Depth of Soil Mixing Layer – The depth of the soil-mixing layer can be an important variable in the inhalation pathway This variable is used to determine what depth within the contaminated zone is actually available for resuspension Its sensitivity is mainly an artifact resulting from the baseline choice for the thickness of the contaminated zone The working group chose to make the mixing layer depth equal to the thickness of the contaminated zone, maximizing the availability of contaminated material for resuspension

Contaminated Fraction, Plant Food – The food ingestion pathway is unique to the Rural Resident scenario The fraction of ingested food that is contaminated is linearly related to the calculated dose and risk for this pathway

Fruit, Vegetable, and Grain Consumption – The food consumption rate is linearly related to the calculated dose and risk for the food ingestion pathway

External Gamma Shielding Factor – The external pathway is a minor contributor to dose and a moderate contributor to risk, as calculated Gamma shielding afforded during periods of indoor occupancy significantly reduces the contribution of this pathway

Density of Contaminated Zone – This variable is non-linearly and indirectly related to the calculated dose and risk for the external pathway As the density of the contaminated zone increases, gamma radiation coming from depth in the contaminated layer of soil is attenuated Its influence on dose is coupled with the "thickness of the contaminated zone" variable, discussed above Since the density of soils at Rocky Flats is relatively uniform, and external exposure is a modest contributor to dose and risk, this variable shows little influence on the modeled results

Annual Average Wind Speed – The annual average wind speed variable directly influences the concentration of radionuclides suspended in the atmosphere and available for inhalation The variable is non-linear with greatest changes evident at lower wind speeds The annual average wind speed at Rocky Flats is a well-characterized and relatively constant quantity

Inhalation Rate – Inhalation rate is linearly related to the dose and risk attributable to the inhalation pathway

Indoor Dust Filtration Factor – The indoor dust filtration factor reduces the inhalation exposure from that which would be received outdoors This variable is most important to the Rural Resident and Office Worker scenarios because of the greater time spent indoors in these scenarios, it plays a similar but lesser role in the Wildlife Refuge Worker scenario

The Area of the Contaminated Zone – This variable is important to both the inhalation exposure pathway and the external exposure pathway The radioactive contamination in the air is determined by a relationship between this contaminated surface area and "mass loading for inhalation " The working group chose a contaminated area large enough to saturate this pathway, that is, to cause its influence to be as great as possible This chosen area is consistent with the actual area of contamination potentially subject to cleanup as a result of this RSAL analysis

Mass Loading for Inhalation – This variable has potential significance to the inhalation pathway, particularly if disturbance to the soil occurs from human activities of natural events The approach used to account for these factors and derive parameter estimates for mass loading is further described in Chapter 4 (Section 4 6) and Appendix A

Exposure Duration – In the RESRAD model, there is no input variable for exposure duration because exposure is modeled over a one-year time period This variable, however, is contained in all of Standard Risk equations to facilitate exposure modeling over a long-term time period In the sensitivity analysis run on the input variables to the Standard Risk equations, exposure duration appeared to be the most influential of all of the variables

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Plant Root Uptake Factor – This variable is used to estimate the concentration of a contaminant that is expected in edible vegetation based on the concentration in soil For rural residents, this factor is a moderate contributor to dose and risk from plutonium and americium, and is a principal contributor to dose and risk from uranium

In addition to these specifically chosen variables, the working group considered potential correlations among selected input variables Relationships between input variables were specified by explicitly calculating one variable as a function of a second variable For example, in the Standard Risk equations for the Wildlife Refuge Worker scenario, outdoor time fraction is calculated as 1 0 minus the indoor time fraction Exposure duration during childhood and adulthood is determined by attributing the first six years to childhood, and the remaining years (total duration minus six years) to adulthood For the probabilistic approach, probability distributions were assumed to be independent Correlations were not used to relate input variables in this assessment For example, the lognormal probability distribution for vegetable consumption rates during childhood is sampled independently from the lognormal distribution for vegetable consumption rates during adulthood for the same individual No significant correlations are anticipated among sensitive-exposure variables for the scenarios evaluated in this assessment While this assumption simplifies the analysis, it may represent a source of uncertainty in the RSAL estimates from the dose- and risk-based approaches

4.4 PROCESS FOR SELECTING AND ASSIGNING PROBABILISTIC DISTRIBUTIONS

As described previously, a sensitivity analysis was performed to identify the variables within each exposure pathway that most strongly influence the calculated RSAL Highly sensitive and moderately sensitive variables are summarized in Section 4-3 Following the conceptual approach shown in Figure 4-7, the RSAL working group evaluated the existing data to determine if a probability distribution could be developed for any or all of these influential variables The existing data can be either site-specific or it can be surrogate data from EPA guidance documents, regional surveys, or the open literature

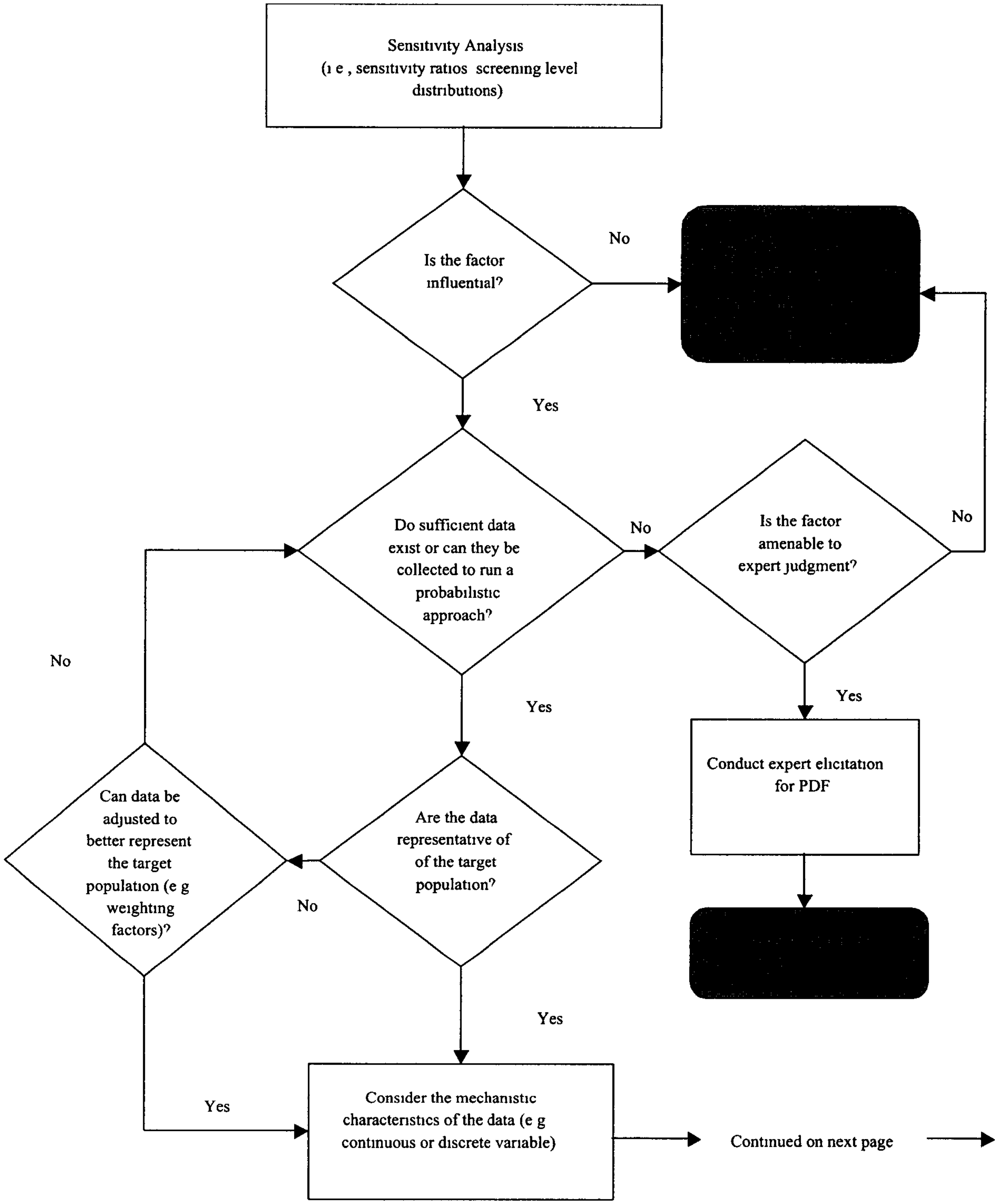

Figure 4-7 Conceptual approach for developing probability distributions (based on U S EPA, 2001b)

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(Continued from previous page)

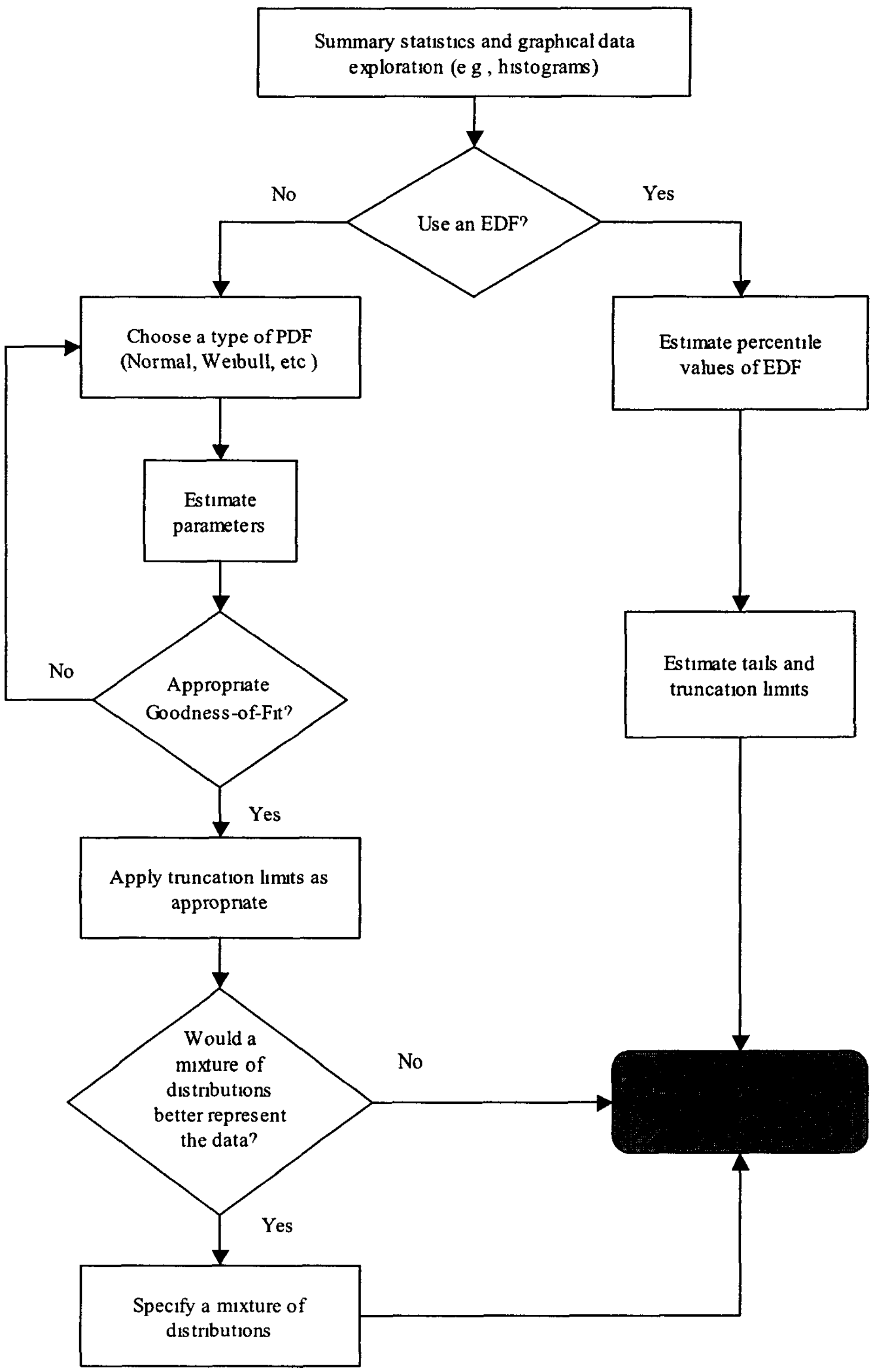

Figure 4-7 Conceptual approach for developing probability distributions (based on U S EPA, 2001b) *(continued)*

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For the majority of variables, such as exposure duration, soil intake rates, and body weight, site-specific data are typically not available If site-specific data are available, they are generally preferable over values reported in the literature, although evaluation of the uncertainties and representativeness of such data is still needed Regardless of whether a data set comes from site-specific measurements or is obtained from published literature, it must be carefully evaluated for applicability to the target population at the site The data set should either be from the target population or from a surrogate population, which is representative of the target population at the site For example, daily-intake rates of produce from an urbanized city in the northeast U S may not be representative of produce intake in a more rural western U S location It would be far preferable to use data sets from western regions to represent residents near Rocky Flats, as was done in this assessment Questions to consider when evaluating the representativeness of a data set include

- What are the populations of interest?
- How, when, and where are those populations exposed?
- What types of activities do the populations engage in?
- What is the overall quality of the data design and collection?

The EPA's *Report of the Workshop on Selecting Input Distributions for Probabilistic Assessments* (U S EPA, 1999b) is a good source for additional information on evaluating representativeness of data sets to a target population, and was used during this evaluation

If, after evaluation, the working group felt that the existing data were not adequate for developing a probability distribution, or the variable was not ranked highly in the sensitivity analysis, a health protective point estimate was selected instead As a rule, the point estimate selected represented a RME or high-end exposed individual For example, the available data on consumption rates for fruits, vegetables, and grain are summarized in the U S EPA *Exposure Factors Handbook* (U S EPA, 1997) in units of grams of food per kilogram body weight per day (g/kg-day) Although the distribution of age-specific body weights has been well studied (U S EPA, 1997), no data were identified to quantify the correlation between consumption rate and body weight Furthermore, preliminary sensitivity analyses (Section 4 2) suggest that the food consumption rate is a moderately sensitive variable As a result, EPA's recommended default body weights for the RME adults (70 kg) and children (15 kg) (U S EPA, 1991) were used to convert the consumption rate data to units of grams per day

Graphical methods, goodness-of-fit tests, and considerations of the mechanistic basis for the biological or physical processes are all techniques that can be used to evaluate and select alternative probability density functions Sometimes more than one distribution may adequately characterize variability or uncertainty In some cases, an empirical distribution function may be preferred over evaluating the fit of alternative probability models to a data set The advantage of an empirical distribution function is that it provides a complete representation of the data with no loss of information and does not depend on the assumptions associated with estimating parameters for other probability models The disadvantage is that an empirical distribution function may not adequately represent the values at the extreme limits of a distribution, especially if the sample size is small and the sampling design is inadequate It is not the intent of this report to describe these processes in detail, however, EPA's *Risk Assessment Guidance for*

Superfund, Volume 3, Part A (U S EPA, 2001b) and the *Report of the Workshop on Selecting Input Distributions for Probabilistic Assessments* (U S EPA, 1999b) are both useful sources of information on fitting and selecting distributions, and were used by the working group in developing distributions

In Appendix A of this report, the process of selecting either a probability distribution or a point estimate for the most influential variables is discussed in detail The most relevant data sets for each exposure variable are briefly summarized, and a qualitative confidence rating is assigned to a comprehensive list of study elements A quantitative description of the probability distribution is presented for use in both RESRAD and Standard Risk equations, along with graphical views of the corresponding probability density function and cumulative distribution function

4.5 POINT ESTIMATES AND PROBABILITY DISTRIBUTIONS FOR EXPOSURE VARIABLES

The results of the input selections for the probabilistic modeling for both the rural residential and wildlife refuge worker are shown in Tables 4-5 and 4-6, respectively Both point estimates and probability distributions are shown in this table For variables described by probability distributions in the probabilistic approach, the distribution type (e g , lognormal, normal, empirical) and the corresponding parameters (e g , mean, standard deviation, minimum, maximum) are also provided In the Excel spreadsheets used to calculate RSAL and risk with the Standard Risk equations (see Appendix C), each input variable includes comment fields with brief descriptions of the data set from which the point estimate or distribution was developed Appendix A gives more details on the data sets evaluated and the methodology used to select and fit distributions

Point estimates and probability distributions for all variables used to calculate RSALs for each land use scenario using RESRAD and Standard Risk equations are presented in the appendices Appendix C contains printouts of the Excel spreadsheets used in the Standard Risk equations, along with instructions for their use Appendix D contains summary tables of the inputs to the RESRAD model

A management decision was made to not develop probabilistic RSALs for the Open Space User and Office Worker scenarios These RSALs are based on a point estimate approach only The inputs to the variables for these two scenarios are shown in the spreadsheets in Appendix C and tables in Appendix D

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Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
Soil ingestion rate	Child	70 Bounded Lognormal-N (1 912, 1 371, 0, 365)	g/yr	200 Lognormal (47 5, 112, 0, 1,000)	mg/day	Calabrese et al (1997) study of Anaconda, MT children (n = 64), Best Linear Unbiased Predictor (BLUP) of one year average - empirical distribution function [{0 10, 0 25, 0 50, 0 75, 0 90, 0 95}, {2, 12, 25, 42, 75, 91}, 0, 150] mg/day, RESRAD unit conversion g/yr = mg/day x 0 001 g/mg x 365 day/yr, then transform to ln(x) and calculate (mean of ln(x), stdev of ln(x)) [parameters of Lognormal-N] Given uncertainty due to sample size, maximum was increased to 1,000 mg/day
	Adult	36 5 Uniform (0, 47 45)		100 Uniform (0, 130)		Calabrese et al (1990) Amherst preliminary adult study (n = 6 subjects for 3 weeks), 4 tracers with best recoveries (Al, Si, Y, Zr) yielded min (> 0) of [1 to17 mg/day] and max of [99 to 216 mg/day], with individual means ranging [5 to 77 mg/day] Tracer average yields a range of 20 to 130 mg/day, which is consistent with *Exposure Factors Handbook* (U S EPA, 1997) plausible range of 30 to 100 mg/day Calabrese et al (1997) Anaconda study (n = 10 subjects for 4 weeks), 5 tracers with best recoveries (Al, Si, Y, Ti, Zr) Best tracer method (BTM) range is [-452 to +797 mg/day] Uniform distribution used to reflect small sample sizes and uncertainty due to prevalence of negative values Lower truncation limit set at 0 to avoid negative values RESRAD units g/yr = mg/day x 0 001 g/mg x 365 day/yr

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Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
	Age – adjusted	43 2 Bounded Lognormal-N (4 464, 0 246, 0, 365)		NA		Mixture distribution based on sum of child (lognormal) and adult (point estimate) weighted by exposure duration, values given assume exposure duration for a child = 6 yrs and exposure duration for an adult = 24 yrs, could be entered with exposure duration as a random variable
Plant ingestion rate, homegrown						
Vegetables, seasonal	Child – total leafy non-leafy	3 2 Lognormal-N (-1 122, 1 775)	kg/yr	10 57 Lognormal (10 57, 50)	kg/yr	*Exposure Factors Handbook* (U S EPA, 1997) (Table 13-33, West), Consumer only Intake of Homegrown Vegetables, Seasonally adjusted (g/kg-day), unit conversions kg/yr = g/kg-day x mean body weight (15 kg) x 0 001 kg/g x 350 day/yr, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 01, 0 10, 0 20, 0 60, 2 58, 7 67, 15 70, 26 46, 46 78}, 0, 58 8], fit to Lognormal Leafy = 14 9%, Non-leafy = 5 1%
	Adult – total leafy non-leafy	6 4 Lognormal-N (0 418, 1 783)	kg/yr	50 Lognormal (50, 240)	kg/yr	Same as child, but for mean body weight = 70 kg, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 04, 0 47, 0 94, 2 79, 12 05, 35 77, 73 26, 123 48, 218 30}, 0, 274 4], fit to Lognormal Leafy = 14 9%, Non-leafy = 85 1%
	Age-adjusted – total leafy non-leafy	5 8 Lognormal-N (2 221, 1 75)	kg/yr	NA		Mixed distribution based on sum of child and adult weighted by exposure duration, values given assume exposure duration for a child = 6 years and exposure duration for an adult = 24 years, could be entered with exposure duration as a random variable Leafy = 14 9%, Non-leafy = 85 1%

Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
Total fruit, seasonal	Child	NA		12 2 Lognormal (12 2, 37 3)	kg/yr	*Exposure Factors Handbook* (U S EPA, 1997) (Table 13-33, West), Consumer only Intake of Homegrown Fruit, Seasonally adjusted (g/kg-day), unit conversions kg/yr = g/kg-day x mean body weight (15 kg) x 0 001 kg/g x 350 day/yr, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 00, 0 30, 0 46, 1 51, 3 61, 9 50, 24 94, 44 84, 76 13}, 0, 96 6], fit to Lognormal
	Adult	NA		57 Lognormal (57, 174)	kg/yr	Same as child, but for mean body weight = 70 kg, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 01, 1 39, 2 16, 7 03, 16 86, 44 35, 116 38, 209 23, 355 25}, 0, 450 8], fit to Lognormal
Total grain	Child	NA		23 65 Lognormal (23 65, 26 4)	kg/yr	*Exposure Factors Handbook* (U S EPA, 1997) (Table 12-1, West), Per Capita Intake of Total Grain Including Mixtures, not Seasonally Adjusted, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 00, 3 6, 5 9, 10 1, 16 4, 26 4, 41 9, 57 2, 102 4}, 0, 135 9], fit to Lognormal
	Adult	NA		110 Lognormal (110, 123)	kg/yr	Same as child, but for mean body weight = 70 kg, empirical distribution function [{0 01, 0 05, 0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 99}, {0 00, 16 9, 27 7, 47 0, 76 7, 123 2, 195 5, 267 1, 477 8}, 0, 634 3], fit to Lognormal
	Age-adjusted	93 Lognormal (93, 98)	kg/yr	NA		Mixed distribution based on sum of child and adult weighted by exposure duration, values given assume exposure duration for child = 6 yrs and exposure duration for adult = 24 yrs, could be entered with exposure duration as a random variable

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Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
Fraction grain homegrown	All ages	0 01	unitless	0 01	unitless	Professional judgment that homegrown grain products will be minimal
Fraction produce that is leafy (Flp)	All ages	0 149	unitless	0 149	unitless	*Exposure Factors Handbook* (U S EPA, 1997), Table 9-21 for West
Non-leafy veg + fruit + grain	Child	42 5 Lognormal-N (2 024,1 042)	kg/yr	21 4 Lognormal (21 4, 56 6)	kg/yr	Sum of Total Veg + Total Fruit + Total Grain x fraction HG (see above) = Log(43, 196) + Log(48, 119) + Log(93, 98) x 0 01, assumes independence in ingestion rates, fit to lognormal PDF Leafy = 14 9%, Non-leafy = 85 1%
	Adult	85 Lognormal-N (3 566, 1 446)	kg/yr	100 7 Lognormal (100 7, 268 3)	kg/yr	Sum of Total Veg + Total Fruit + Total Grain x fraction HG (see above) = Log(43, 196) + Log(48, 119) + Log(93, 98) x 0 01, assumes independence in ingestion rates, fit to lognormal PDF Leafy = 14 9%, Non-leafy = 85 1%
	Age-adjusted	76 5 Lognormal-N (3 438, 1 416)	kg/yr	NA		Sum of Total Veg + Total Fruit + Total Grain x fraction HG (see above) = Log(43, 196) + Log(48, 119) + Log(93, 98) x 0 01, assumes independence in ingestion rates, fit to lognormal PDF Leafy = 14 9%, Non-leafy = 85 1%
Soil-to-Plant Transfer Factor for Pu-239 and Am-241	All Ages	Pu-239 (5 8 x 10^{05}) Am-241 (1 2 x 10^{03})	unitless	Leafy Pu-239 (2 35x10^{03}) Am-241(5 2x10^{02}) Non-leafy Pu-239 (2 5x10^{04}) Am-241(4 5x10^{03})	unitless	Based on Whicker, 1999 RESRAD inputs are in wet weight units combine estimates for leafy vegetables (15%) and non-leafy vegetables, fruit, and grain (85%) Risk-based inputs are in dry weight units and distinguish between leafy vegetables versus non-leafy vegetables, fruit and grain

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Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
Soil-to-Plant Transfer Factor for Uranium	All Ages	0 006 Lognormal-N (-6 8355, 1 0893)	unitless	0 0513 Lognormal (0 0155, 0 0233)	unitless	Combines multiple study estimates representing various soil types, plant types, and dry weight conversion factors Both RESRAD and Risk-based inputs combine leafy, non-leafy, fruit, and grain Point estimates are arithmetic (not logarithmic) values
Inhalation rate	Child	5,256 Lognormal-N (8 084, 0 305)	m^3/yr	8 3 Lognormal (9 3, 2 9)	m^3/day	Allan and Richardson (1998) and review of *Exposure Factors Handbook* (U S EPA, 1997) recommendations
	Adult	8,400 Lognormal-N (8 657, 0 237)		20 Lognormal (16 2, 3 9)		Allan and Richardson (1998) and review of *Exposure Factors Handbook* (U S EPA, 1997) recommendations
	Age-adjusted	7,771 Lognormal-N (8 573, 0 207)		NA		Assumes exposure duration for child = 6 yrs, exposure duration for adult = 24 yrs
Occupancy factor	All ages	1 0	unitless	NA		Intake rates are specific to the resident, therefore, intake rates do not need to be adjusted
Exposure time	All ages	NA		24 0	hrs/day	Professional judgment that all of the potential exposure occurs during a full day
Exposure frequency	All ages	incorporated into time fractions indoors and outdoors		350 Triangular (175, 234, 350)	days/yr	Central tendency exposure (CTE) default of 234 d/yr based on *Exposure Factors Handbook* (U S EPA, 1997), 64% of time spent at home, truncation limits are professional judgment that max time is 7 days/wk x 50 wk/yr, minimum is 50% of max
Exposure duration[1]	All ages	NA	years	30 Truncated Lognormal (12 6, 16 2, 1, 87)	years	*Exposure Factors Handbook* (U S EPA, 1997), Table 15-167, Residential Occupancy Period (ROP), empirical distribution function [{0 10, 0 25, 0 50, 0 75, 0 90, 0 95, 0 98, 0 99}, {2, 3, 9, 16, 26, 33, 41, 47}, 1, 87], fit to lognormal

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Table 4-5 Summary of point estimates and probability distributions used in the Rural Resident scenario

Exposure Variable	Age Group	Input for RESRAD 6 0 Point Est (and PDF)	Units	Input for Standard Risk Equations Point Est (and PDF)	Units	Source and Comments
Mass Loading	All ages	0 000067 empirical distribution function divided by 1,000 - see notes	g/m^3	67 Empirical distribution function - see notes	$\mu g/m^3$	Empirical distribution function based on site-specific data and professional judgment Units converted to $\mu g/m^3$ [{0, 20 2, 23 1, 50 7, 58 0, 95 7, 109 5, 200},{min, 0 338, 0 788, 0 919, 0 944, 0 969, 0 994, max}]
Indoor time fraction (F_{in})	All ages	0 85	unitless	0 85	unitless	*Exposure Factors Handbook* (U S EPA, 1997) (Tables 15-131 and 15-132), Minutes Spent Indoors and Outdoors (all populations), 75th percentiles 1,235 minutes indoors + 210 minutes outdoors = 1,445, ~ 1,440 minutes/day (24 hrs)
Outdoor time fraction (F_{out})	All ages	0 15	unitless	0 15	unitless	
Indoor dust filtration factor	All ages	0 7	unitless	0 7	unitless	Average of indoors (0 4) described in *Soil Screening Level Guidance for Radionuclides* (U S EPA, 2000) and Default in RESRAD, and outdoors (1 0), assumes resident will spend time indoors, where windows and doors will be open during summer months
External gamma shielding factor	All ages	0 4	unitless	0 4	unitless	*Soil Screening Guidance for Radionuclides* (U S EPA, 2000)

[1]Exposure duration may be entered as a random variable in RESRAD 6 0, the set of input values for all exposure variables are determined for Year 1, and applied across all years throughout the exposure duration
PDF = probability density function, NA = not applicable

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Table 4-6 Summary of point estimates and probability distributions used in Wildlife Refuge Worker scenario

Exposure Variable	Input for RESRAD 6 0 Point Est (and PDF)*	Units[1]	Input for Standard Risk Equations	Units	Source and Comments
Soil ingestion rate (IRs)	109 5 Uniform (0, 142 4)	gm/yr	100 Uniform (0, 130)	mg/day	Calabrese et al (1990) Amherst preliminary adult study (n = 6 subjects for 3 weeks), 4 tracers with best recoveries (Al, Si, Y, Zr) yielded min (> 0) of [1 to 17 mg/day] and max of [99 to 216 mg/day], with individual means ranging [5 to 77 mg/day] The 4 best tracers were averaged to arrive at a range of 0 to 130 mg/day A uniform distribution was used to account for the low confidence in the data based *Exposure Factors Handbook* (U S EPA, 1997) cites BTM and plausible range of 30 to 100 mg/day, which is consistent with Superfund defaults of 50 mg/day (non-contact intensive) and 100 mg/day (reasonably maximally exposed)
Inhalation rate (IRa)	14,000 Beta (9,636, 17,560, 1 79, 3 06)	m^3/yr	1 3 1 1 + (2 0 - 1 1) x Beta (1 79, 3 06)	m^3/hr	Survey of 20 biological workers at 4 wildlife refuges who spent at least 50% of their time on-site, outside PDF generated combining average breathing rates for each reported activity {light, medium, and heavy activity (1 1, 1 3, and 2 0 m^3/hr)} Best-fit for beta (chi-square = 0 175), shape parameters are given and yields values between 0 and 1 0, for Crystal Ball®, modify for scale using min + (max-min) x beta, for @Risk, modify for scale using min + beta
Occupancy factor	1 0	unitless	NA		Intake rates are specific to the wildlife refuge worker, therefore, intake rates do not need to be adjusted
Exposure time	NA		8 0	hrs/day	Professional judgment that all of the potential exposure occurs during a full workday

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Table 4-6 Summary of point estimates and probability distributions used in Wildlife Refuge Worker scenario

Exposure Variable	Input for RESRAD 6 0 Point Est (and PDF)*	Units[1]	Input for Standard Risk Equations	Units	Source and Comments
Exposure frequency	NA		250 Truncated Normal (225, 10 23, 200, 250)	days/yr	Rocky Mountain Arsenal report summarizing survey data for biological workers (n = 20) (pp B 3-149 - 150), truncation limits are professional judgment that minimum full time work is 4 days/wk x 50 wks/yr, Max is five days/wk x 50 wks/yr (Ebasco, 1994)
Exposure duration[1]	NA	years	18 7 Truncated Normal (7 18, 7, 0, 40)	years	Rocky Mountain Arsenal report summarizing survey data for biological workers (n = 20) (pp B 3-172-175), truncation limits are professional judgment that values are nonnegative and within five standard deviations (SD's) of the mean (Ebasco, 1994)
Mass loading	0 000067 empirical distribution function divided by 10^6 see notes	g/m^3	67 empirical distribution function - see notes	$\mu g/m^3$	Empirical distribution function derived by working group based on site-specific data for fire and non-fire years Units converted to $\mu g/m^3$ [{0, 20 2, 23 1, 50 7, 58 0, 95 7, 109 5, 200},{min, 0 338, 0 788, 0 919, 0 944, 0 969, 0 994, max}]
Indoor time fraction (F_{in})	0 5	unitless	0 5	unitless	Rocky Mountain Arsenal survey states ~ 0 5 time spent indoors (Ebasco, 1994)
Outdoor time fraction (F_{out})	0 5	unitless	0 5	unitless	
Indoor dust filtration factor	0 4	unitless	0 4		Assumes office environment without open windows *Soil Screening Level Guidance for Radionuclides* (U S EPA, 2000)
External gamma shielding factor (see comment)	0 4	unitless	0 4	unitless	*Soil Screening Level Guidance for Radionuclides* (U S EPA, 2000)

[1]Exposure duration may be entered as a random variable in RESRAD 6 0, the set of input values for all exposure variables are determined for Year 1, and applied across all years throughout the exposure duration
PDF = probability density function, NA = not applicable

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4.6 DESCRIPTION OF PROBLEM RELATED TO MASS LOADING

The dose and risk model outputs that were ultimately used by the working group to produce RSALs incorporated the same mass loading variable across all scenarios This probability distribution includes the effects of changes in land use, the possibility of drought, and the possibility of grassland fire Though based on site-specific and regional measurements of ambient mass loading, the potential increases to the mass loading distribution had to be developed from a diverse group of sources The following sections provide a detailed explanation of the evolution of parameter estimates for mass loading

4 6.1 PROBLEM STATEMENT

In order to adequately describe the mass loading variable needed to represent future conditions, a conceptual model evolved as illustrated in Figure 4-8 The model presents several different conditions that might occur as a result of changes in land use As a base condition the working group used current conditions at Rocky Flats From that base condition, predictable effects of possible tilling and light recreational vehicle or horseback riding usage were considered Such uses would be possible in all scenarios, to some extent, and were considered as a multiplier on the base case Any resulting modified mass loading will be referred to in this discussion as the "scenario mass loading " Other modifications to the scenario mass loading are driven by more specific events, such as periods of reduced rainfall (drought-like conditions) or periods following a fire during which the soil would erode more easily due to wind These infrequent, but possibly significant occurrences were represented as random periodic modifications to the scenario mass loading In other words, variability in mass loading can be described by a probability distribution that combines site-specific data with judgment about the frequency and influence of modifying conditions

The airborne concentration of respirable particulate matter (PM-10) in the vicinity of Rocky Flats is well characterized, varying from a low of about 9 4 micrograms per cubic meter ($\mu g/m^3$) to a high of about 16 6 $\mu g/m^3$, with a median of around 11 6 $\mu g/m^3$, based on the five most recent years of available PM-10 data from CDPHE The PM-10 air monitoring data from Rocky Flats and the State of Colorado are provided in Appendix F While this is a well-characterized distribution, the air monitors used to develop this distribution were located in areas with very little surface disturbance This distribution does not necessarily represent potential increases to the annual mass loading that might be experienced by a future receptor at Rocky Flats under all reasonably foreseeable conditions For example, more frequent routine soil disturbances or increased wind erosion as the aftermath of a wildfire that denudes vegetation from large expanses of the soil surface would not be represented in the existing data In this circumstance, other information must be sought to extend the observations to conditions for which there are no site-specific data Since such estimates cannot possibly result in a single value that is known with precision, and because the range of possible values could be quite large, the mass loading for inhalation can be best represented by a probability distribution of values This distribution can be estimated from available mass loading data by determining the probability of a wildfire on-site in any random year, and developing a weighted-average distribution that represents potential mass loadings during both fire and non-fire years Details regarding the methods used

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to develop the distribution for mass loading using in RESRAD and Standard Risk equations are given in Appendix A

Two mass-loading distributions are necessary for input into the RESRAD model, the first representing respirable particulate matter and the second representing the particulate matter that is available for deposition onto plants The first was derived based on site-specific and statewide PM-10 data, that is, data for air concentrations of particulate matter less than 10 micrometer (µm) aerodynamic diameter which are more easily admitted to the respiratory tract of humans The second, total suspended particulate (TSP) matter can be derived from the first by assuming a direct correlation with PM-10, based on site-specific data Studies of the mechanics of inhalation actually show that particles with aerodynamic diameters greater than about 2 5 µm are unlikely to reach the lower respiratory tract (Godish, 1991) For the particles that do enter the lower respiratory tract, an even smaller fraction is actually deposited in the lungs (Godish, 1991) Particles that do not reach the lungs will be either expelled or ingested Ingested particles are included in the soil ingestion rate variable Data are not available to determine what fraction of PM-10 particles are included in the 2 5 µm fraction, thus the working group elected to include all particulate matter smaller than 10 µm in determining the potential dose and risk, even though this is likely to significantly overestimate the contribution of these particles

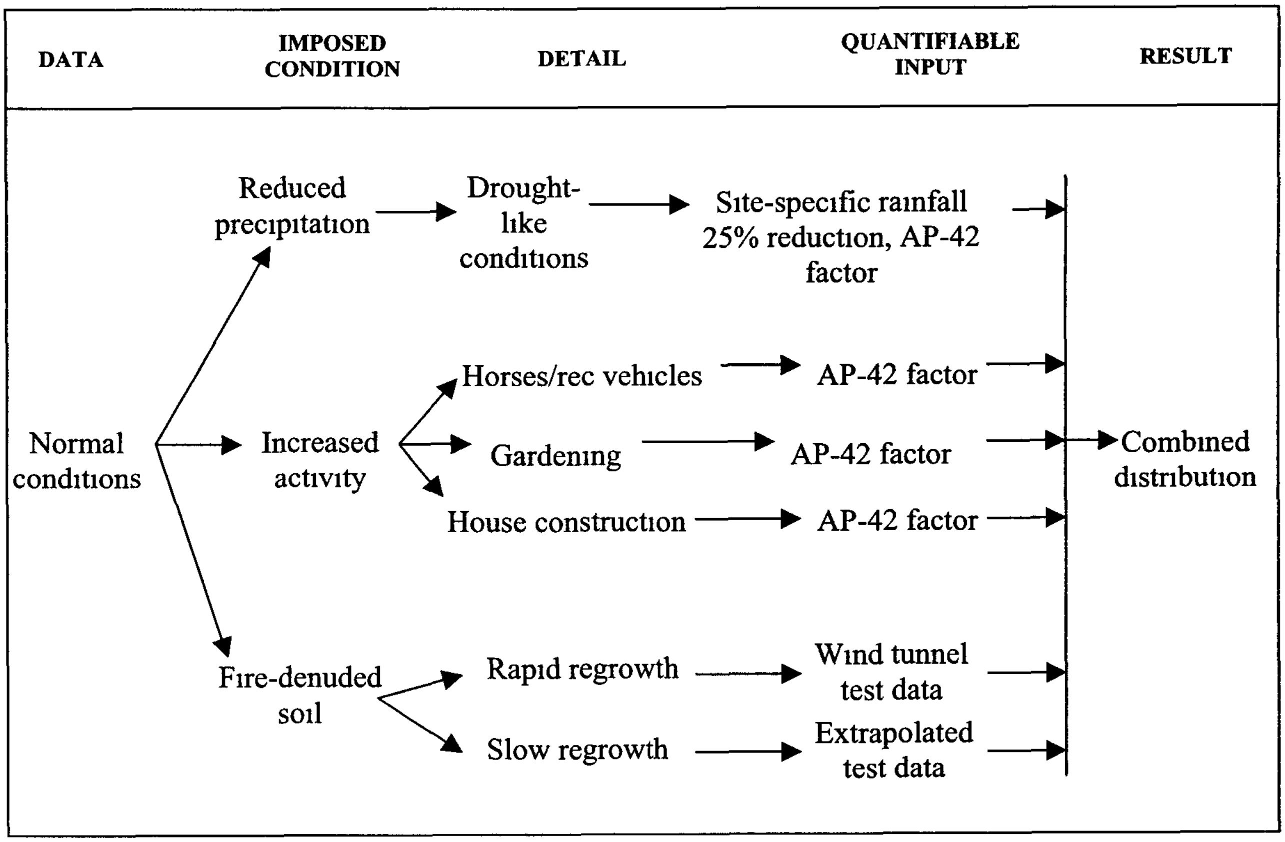

Figure 4-8 Conceptual Model of factors that impact the variability in mass loading [1]

[1] AP-42 – EPA Publication *Compilation of Air Pollutant Emission Factors* (U S EPA, 1995), a handbook that provides a comprehensive compendium of empirically-based emission factors and calculational algorithms for estimating airborne emissions from a variety of anthropogenic activities, mostly for industrial and transportation settings

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4.6.2 DESCRIPTION OF DATA AVAILABLE

The mass loadıng at Rocky Flats has been measured for a number of years The most recent and probably most representatıve measurements of mass loadıng ın the area around Rocky Flats are from CDPHE's five-statıon network surroundıng the penmeter of Rocky Flats Sıx years of PM-10 data are avaılable (1995–2000) and have been used to depıct the dıstrıbutıon of annual average mass loadıng at Rocky Flats (see Appendıx F) The annually averaged data are descrıbed by a dıstrıbutıon whose range ıs from 9 4 $\mu g/m^3$ to 16 6 $\mu g/m^3$ wıth a medıan value of 11 6 $\mu g/m^3$ Thıs mass loadıng may be compared to measurements of statewıde PM-10 annually averaged mass concentratıons rangıng from 6 7 $\mu g/m^3$ to 51 4 $\mu g/m^3$, wıth a medıan of 20 3 $\mu g/m^3$ (U S EPA, 2001a) (see Appendıx F) Clearly, the exıstıng mass concentratıons at Rocky Flats are among the lowest ın the state It ıs noted that the statewıde data are lıkely to be somewhat bıased to hıgher mass loadıng condıtıons, due to the cnterıa generally used to sıte such monıtorıng statıons These sıtıng crıterıa dıctate that the statıons be located ın areas more lıkely to experıence aır qualıty problems Data from the CDPHE database for Rocky Flats also show that TSP can be lınearly regressed agaınst the PM-10 concentratıons wıth a slope of approxımately 2 5 (see Appendıx F) Thıs value of 2 5 was used as a dırect multıplıer to derıve the TSP dıstrıbutıon used to characterıze plant deposıtıon from the PM-10 dıstrıbutıon

4.6.3 OTHER INFORMATION AVAILABLE

The lıterature offers a number of sources from whıch to buıld an estımate of mass loadıng These sources can provıde varıous mathematıcal factors that are descrıptıve of processes causıng ıncreased resuspensıon of soıls due to varıous soıl dısturbance mechanısms A well-documented source of such ınformatıon ıs contaıned ın background ınformatıon provıded for EPA's *Compılatıon of Aır Pollutant Emıssıon Factors* (AP-42) (U S EPA, 1995) In partıcular, ıts dıscussıons related to the generatıon of fugıtıve dust, and the ınfluence of precıpıtatıon on dust generatıon was especıally pertınent (MRI, 1998) Also ın AP-42 are descrıptıons of other dust generatıng actıvıtıes that appear suıtable as surrogates for future actıvıtıes that mıght be observed at the sıte Also, there ıs lıterature avaılable through the Natıonal Drought Mıtıgatıon Center (NDMC, 1995) and through state resources relatıng the ıncıdence of drought to the meteorologıcal data that are avaılable from sıte-specıfic measurement programs

Fınally, related to the fire-aftermath, the Sıte contracted URS Corporatıon, ın conjunctıon wıth Mıdwest Research Instıtute (MRI), to conduct a wınd-erosıon study to develop sıte-specıfic measurements of erosıon potentıal that could be used to estımate potentıal post-fire mass loadıng ıncreases on an annual basıs These results are presented ın two reports The first (MRI, 2001a) deals wıth the erosıon potentıal and ıts changes wıth tıme The second (MRI, 2001b) characterızes the relatıve concentratıons of radıonuclıdes observed ın the source soıl and ın the aırborne eroded soıl Both are pertınent to the RSAL calculatıons

4.6 4 QUANTIFICATION OF PROBABILISTIC EVENTS

The probabılıty dıstrıbutıon for mass loadıng was derıved from four factors the scenarıo mass loadıng as a baselıne, a low-precıpıtatıon case, a sprıng-fire case, a fall-fire case

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First, the scenario mass loading was developed Data relating the rate of emissions to soil-disturbing activities, suggest that the present-day mass loading at the site could be expected to increase by as much as a factor of two (see Appendix F) due to moderate activities such as gardening, or use of light recreational vehicles or horses While certainly coincidental, increases of this magnitude are consistent with the difference between the present 11 6 $\mu g/m^3$ median observed at the Site, and the state-wide median of 20 2 $\mu g/m^3$ The latter mass loading has been used as the scenario mass loading from which the probability distribution was developed

A significant deficiency in rainfall can cause increased wind erosion of surface soil, even from vegetated areas Site-specific data suggest that a reduction of 25% in annual rainfall, indicative of the onset of drought-like conditions (NDMC, 1995), occurs about 15% of the time, based on a data set spanning 37 years at the Site (see Appendix F) For purposes of developing a probability distribution, the working group assumed that deficiencies in rainfall, to represent dryer than normal conditions, would influence about 25% of all modeled occurrences The dust emission factor during such periods was adjusted upward about 14% based on guidance contained in AP-42 (MRI, 1998, p 2-2) The calculation is simple—for days with precipitation equal to at least 0 01 inches, fugitive dust is suppressed, and days with less than 0 01 inches of rain emit fugitive dust Suppression from light snowfall was not considered The site-specific data were used to derive estimates of precipitation days in normal and dry years

Data from wind-tunnel studies conducted after the 50-acre test burn at Rocky Flats in Calendar Year 2000 (CY2000) provided estimates of erosion potential at different times following the grass fire A springtime fire on the site can be expected to cause an annual increase in erosion potential of about 2 5 times the potential without a fire (see Appendix F) due to removal of vegetation that provides a natural barrier to wind In other words, after a springtime fire, the annually averaged mass loading should increase about 2 5 times Within the next year or so, however, conditions would be expected to become normal Extrapolation of these same data to a fire that might occur in the fall suggests that annual emissions would increase about 4 7 times, the fall timing presenting less favorable conditions for vegetative recovery

Based on the frequency of burns outlined in the Site's proposed controlled burn plan (DOE, June 2000) it has also been assumed that these fires could potentially involve a contaminated area once every 10 years Half of those fires have been assumed to occur in the spring (warm seasons) when recovery is more rapid, and half have been assumed to occur in the fall (cold seasons), with slower recovery This rate of fire occurrence is much greater than would be estimated for wildfires that might be caused by lightning or other causes, based on statewide data describing wildfire frequency (CO State Forest Service, 1999) Members of the working group also noted that controlled burns would not normally be prescribed in the fall, but such occurrences have been retained so as not to exclude wildfire events The assumption of relatively frequent fall controlled-burn events constitutes a conservative assumption in the model, as does the initial assumption of an average frequency of 10 years on the contaminated area The 10-year frequency assumption overestimates both observed fire frequency in the Front Range based on acreage, and estimated frequency based on the relative area of the contaminated zone compared to the area of the site

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4.6.5 FINAL EMPIRICAL DISTRIBUTION FUNCTION

These probabilistic events were combined in a form that could be used by RESRAD and EPA's Standard Risk equations, specifically in the form of a discrete "continuous linear" (RESRAD's designation) distribution This type of distribution is also referred to in the statistics literature as an empirical distribution function, or an empirical cumulative distribution function The development of this distribution is detailed in Table 4-7 The eighth column in this table, labeled Grand Frequency, shows that the scenario mass-loading base conditions would be expected at Rocky Flats approximately 67 5% of the time, with dry weather influencing this base condition about 22 5% of the time Post-fire conditions, occurring in the upper 10% of the mass loading distribution are divided such that 90th to 95th percentile conditions are dominated by spring recovery events, including influence by dryer conditions, and 95th and greater percentiles are dominated by fall recovery events The minimum and maximum values (zero and 100th percentile conditions) needed to completely specify the empirical distribution function , are 10 $\mu g/m^3$ and 200 $\mu g/m^3$, respectively The minimum is given as the low-mass loading observed in site-specific measurements and the maximum is based on the maximum value observed in the statewide PM-10 mass data, increased by a factor of about four This value may be somewhat more consistent with a possible fall-fire maximum value The extremes of the distribution have little actual influence on the RESRAD or risk calculations, since the probability of such extreme occurrences is negligible The 95th percentile (67 $\mu g/m^3$) was used for point estimate calculations

Table 4-7 Frequency distribution matrix showing derivation of empirical cumulative frequency distribution for mass loading Minimum and maximum values are not shown

Fire	Weight	Freq.	Precip	Weight	Freq	Grand Weight	Grand Freq	Mass Loading ($\mu g/m^3$)	Cum Freq
None	1 0	0 90	Normal	1 0	0 75	1 0	0 6750	20 2	0 338
None	1 0	0 90	Dry	0 14	0 25	1 14	0 2250	23 1	0 788
Spring	2 51	0 05	Normal	1 0	0 75	2 51	0 0375	50 7	0 919
Spring	2 51	0 05	Dry	0 14	0 25	2 87	0 0125	58 0	0 944
Fall	4 74	0 05	Normal	1 0	0 75	4 74	0 0375	95 7	0 969
Fall	4 74	0 05	Dry	0 14	0 25	5 42	0 0125	109 5	0 994

Freq = frequency, Precip = precipitation, Cum Freq = cumulative frequency

4.7 SELECTION OF CANCER SLOPE FACTORS

The EPA classifies all radionuclides as Group A (known) human carcinogens based on their property of emitting ionizing radiation and on extensive evidence from epidemiological studies of radiogenic cancers in humans (U S EPA, 2001a) At Superfund sites with radioactive contamination, EPA generally evaluates potential human-health risks based on the radiotoxicity, i e , adverse health effects caused by ionizing radiation, rather than on the chemical toxicity of each radionuclide present An exception is uranium, where both radiotoxicity and chemical toxicity should be evaluated (U S EPA, 2001a) Usually only carcinogenic effects of radionuclides are considered because, in most cases, cancer occurs at lower doses than either mutagenesis or teratogenesis

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In order to evaluate the likelihood of cancer from exposure to individual radiogenic carcinogens, EPA's Office of Radiation and Indoor Air calculates cancer slope factor values for each individual radionuclide, based on its unique chemical, metabolic, and radioactive properties The cancer slope factors used in these risk calculations were obtained from Office of Radiation and Indoor Air's most current (April 16, 2001) Health Effects Assessment Summary Tables (HEAST) and were, in large part, based on the risk coefficients derived in Federal Guidance Report No 13, "*Cancer Risk Coefficients for Environmental Exposure to Radionuclides*" (U S EPA, 1999b) The only exceptions are the cancer slope factors for the soil ingestion pathway, which were not derived in Federal Guidance Report No 13 The Office of Radiation and Indoor Air derived the cancer slope factors for the soil ingestion pathway in a parallel fashion to those presented in Federal Guidance Report No 13 for the other pathways

A cancer slope factor is an estimate of the probability of an individual developing cancer per unit intake of, or external exposure to a specific carcinogen over a lifetime Inhalation and ingestion cancer slope factors for radionuclides are central estimates in a linear model of the age-averaged, lifetime radiation cancer risk for incidence of both fatal and nonfatal cancers per unit of activity ingested or inhaled These cancer slope factors are expressed as risk per picoCurie (U S EPA, 2001a) External exposure cancer slope factors for radionuclides are central estimates of the lifetime radiation cancer incidence risk for each year of exposure to external radiation from radionuclides distributed uniformly in a thick layer of soil The units for these external radiation slope factors are expressed as risk/yr per pCi/g soil (U S EPA, 2001a) Thus, a cancer slope factor is similar to a dose conversion factor, but instead of assigning a unit dose for every unit of exposure (mrem/pCi), a unit of risk is assigned for every unit of exposure (probability of adverse effect/unit radioactivity) Dose conversion factors are discussed in Section 4 8

Cancer slope factors can be used to estimate lifetime-cancer risks to members of the general population due to radionuclide exposures, when combined with site-specific media concentration data and appropriate exposure assumptions The EPA risk assessment methodology (U S EPA, 2000) calculates the lifetime-cancer risk associated with a radionuclide intake or external exposure as the product of the estimated lifetime intake, or external exposure to, a particular radionuclide and the radionuclide-specific cancer slope factor This calculation presumes that risk is directly proportional to intake or exposure, i e , it follows a linear, no-threshold model Current scientific evidence does not rule out the possibility that risks from environmental exposure levels calculated this way may be over- or under-estimated However, several recent expert panels (UNSCEAR, 1993, 1994, NRPB, 1993, NCRP, 1997) have concluded that the linear, no-threshold model is sufficiently consistent with the current understanding of carcinogenic effects of radiation that its use is scientifically justified for estimating risks from low doses of radiation This linear, no-threshold model is universally used for assessing the risk from environmental exposure to relatively low environmental concentrations of radionuclides as well as to other carcinogens (below a risk of approximately 10^{-2}) (U S EPA, 1999b)

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The EPA has calculated cancer slope factors for most radionuclides Different radionuclides generally have different slope factors The slope factors also vary depending on route of exposure Therefore, risk associated with inhaling 1,000 pCi of uranium is different from that of inhaling 1,000 pCi of cesium Also, the risk associated with inhaling 1,000 pCi of radium is different from that of ingesting 1,000 pCi of radium via drinking water

The radiation risk coefficients for cancer incidence that are the basis for the new cancer slope factors in HEAST incorporate the state-of-the-art models and methods developed in ICRP 60 through 72 (U S EPA, 2001a) These new models take into account age and gender differences in radionuclide intake, metabolism, dosimetry, radiogenic risk, and competing causes of death They are intended to apply to the general public who may be exposed to low-levels of radionuclides in the environment These new risk coefficients incorporate

- The most recent epidemiological evidence for cancer risk,
- Updated vital statistics from the 1989-91 U S decennial life tables, which define survival rates for an average person in the population,
- Improved biokinetic and dosimetry models from ICRP 60 through 72, which increase the predicted quantities for ingestion and decrease the predicted quantities for inhalation,
- More relevance to the general public – for internal doses, they incorporate age- and gender-specific absorbed dose rates, usage data, and risk coefficients for specific cancer sites over the lifetime of the exposed population,
- Most recent external dosimetry (based on Federal Guidance Report No 12), which still is based on dose rates calculated for a reference adult male, applied to all ages and genders (U S EPA, 1993), and
- The lung absorption type (M) and gastrointestinal (GI) fractional-absorption coefficient recommended by ICRP 71 (ICRP, 1995b) for environmental exposures to plutonium and americium

Initially, the RSALs were calculated using age-weighted cancer slope factors for all of the exposure scenarios Several peer reviewers commented that it was inappropriate to use slope factors that incorporated both childhood and adult biokinetics and dosimetrics to model risk for adult only exposure scenarios such as the Wildlife Refuge Worker and the Office Space Worker For these scenarios, the RSALs were re-calculated using adult specific (e g , ages 18 to 65 years) slope factors provided by Phil Newkirk with EPA's Office of Radiation and Indoor Air (Newkirk, 2002) RSALs for the Rural Resident and Open Space User scenarios were calculated using the age-weighted cancer slope factors Young children, as well as adults, are expected to be exposed in both of these scenarios, and were evaluated by age-averaging the exposure Table 4-8 summarizes the cancer slope factors used in the Standard Risk calculations of RSALs

Table 4-8 Cancer slope factors used in risk-based calculations of RSALs

Isotope	Age Group[1,2]	Oral/Ingestion (risk/pCi)	Inhalation (risk/pCi)	External (risk/yr per pCi/g)
Am-241	All ages	2 17 x 10^{10}	2 81 x 10^{8}	2 76 x 10^{8}
	Adults only	9 10 x 10^{11}		
Pu-239	All ages	2 77 x 10^{10}	3 33 x 10^{8}	2 00 x 10^{-10}
	Adults only	1 21 x 10^{10}		
U-234	All ages	1 58 x 10^{10}	1 14 x 10^{-8}	2 52 x 10^{10}
	Adults only	5 11 x 10^{11}		
U-235	All ages	1 57 x 10^{10}	1 01 x 10^{8}	5 18 x 10^{-7}
	Adults only	4 92 x 10^{11}		
U-238	All ages	1 43 x 10^{10}	9 32 x 10^{-9}	4 99 x 10^{11}
	Adults only	4 66 x 10^{11}		

[1]Cancer slope factors for all ages are relevant to the Rural Resident and Open Space User scenarios
[2]Cancer slope factors for adults only are relevant to the Wildlife Refuge Worker and Office Worker scenarios

4.8 SELECTION OF DOSE CONVERSION FACTORS

The RESRAD computer code requires the creation of and specification of a library of dose conversion factors, which is used for dose calculations Separate values for dose per unit of radioactivity inhaled or ingested need to be specified for each isotope for which dose calculations are performed Several isotopes of concern at Rocky Flats (notably the isotopes of plutonium) have different dose conversion factors depending on their physical form and their consequent behavior in the body (rate of absorption into the blood, rate of clearance from the lung, target organs, etc) Decisions were made as to which dose conversion factors were appropriate

The computation of dose conversion factors is fairly complicated, and requires the use of a separate model (outside the scope of RESRAD) ICRP is a recognized body of experts from all areas in the field of health physics that is tasked with developing and refining guidance on radiation protection, including the calculation of dose conversion factors for radioisotopes The ICRP periodically reviews the experimental literature, updates its model assumptions about the way radioisotopes behave inside the body, revises its radiation protection guidance and/or revises the values of the dose conversion factors based upon the best available science at the time, and publishes its proceedings in numbered publications The ICRP is recognized by all U S regulatory agencies (NRC, DOE, and EPA) as a highly credible source of radiation protection guidance

ICRP originally created dose conversion factors for radioisotopes entering the body in its ICRP 2 for worker exposure (ICRP, 1959), there have been two comprehensive revisions since then The first revision is captured in ICRP 26 and 30 for worker exposure (ICRP, 1977, 1979) The second and most recent revisions are published in ICRP 60 through 72 with compilations of dose conversion factors in ICRP 68 (ICRP, 1994b) for worker exposure and ICRP 72 for exposure of the public (ICRP, 1996) Because of the timing of these revisions, the 1996 calculations of RSALs utilized the dose conversion factors from ICRP 30 (ICRP, 1979), and the RAC utilized

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the dose conversion factors from ICRP 72 (ICRP, 1996) Since the later dose conversion factors are based upon a more complete research base, and are explicitly applicable to environmental exposure of the public as opposed to radiation worker exposure, they are being used in the current calculations

4 8.1 DIFFERENCES BETWEEN ICRP 30 AND ICRP 72 DOSE CONVERSION FACTORS

The ICRP 72 (ICRP, 1996) dose conversion factors represent a culmination of several revisions of the model and methodology used to compute doses in ICRP 30 (ICRP, 1979) The most significant changes include the development of dose conversion factors specific to various age groups, the revision of the lung model itself, a more extensive set of tissue-weighting factors (which are used to calculate dose to the whole body and is equivalent to the sum of doses to individual organs) and revisions to certain ingestion dose conversion factor selection options (including plutonium) that reflect the greater uncertainty inherent in environmental exposure to ingested radionuclides

The revision of the lung model represents a refinement of the assumptions about distribution of inhaled radionuclides in the body Consideration is given to the particle-size distribution in the inhaled aerosol and its deposition, transfer and site-specific exposure to the various parts (compartments) of the system mouth/nose, esophagus, tracheobronchia, alveoli, lymph, and blood As far as actinides are concerned, particularly plutonium, the revision of the lung model has the effect of somewhat increasing the inhaled, cleared and swallowed fraction, while reducing the fraction which deposits in and is retained in the lung—the dose conversion factor for inhalation decreases by a factor of 2 to 5, depending on clearance/absorption category from the dose conversion factor in ICRP 30 (see Table 4-9)

The addition of a number of tissue-weighting factors generally has the effect of reducing the effective dose equivalent resulting from exposure of the principle organs affected by ingested plutonium (liver and bone surfaces) This is due to two facts the weighting factor for bone surfaces was reduced by a factor of three in the light of later research, and the apportionment of the ICRP 30 (ICRP, 1979) "remainder of the tissues in the body" factor of 0 3 to a number of specific organs (liver 0 05) has the effect of reducing the liver dose contribution by a factor of six

The revision in the value of the gastrointestinal uptake fraction (f1) for plutonium has the effect of significantly increasing the ingestion dose coefficient The single value for f1 in ICRP 72 (ICRP, 1996) is 50 times higher than the lowest f1 in ICRP 30 (ICRP, 1979), this offsets the effect of the tissue-weighting factors described above The net effect is to increase the ingestion dose conversion factor for plutonium (all compounds) by a factor of about 18 over the dose conversion factor for plutonium oxide that was used previously (see Table 4-10)

For plutonium (and for americium to a lesser degree) the overall change resulting from the modifications in ICRP 72 (ICRP, 1996) is to increase the relative importance of ingested plutonium over inhaled plutonium to dose contribution

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4.8.2 CHOICE OF LUNG ABSORPTION TYPE FOR INHALATION DOSE CONVERSION FACTOR FOR PLUTONIUM

An additional change resulting from the revision of the lung model in ICRP 60 through 72 is that the system of lung clearance classes from ICRP 30 (ICRP, 1979) (Y, W, D representing year, week, and day timeframes for clearance of inhaled material from the lung) are replaced with a system of lung absorption types (S, M, F for slow, medium, and fast, respectively, absorption from the lung to the blood) While there are parallels between these two systems, they are not identical, since clearance is a combination of both mechanical removal and absorption to the blood In addition, the boundary criteria for selecting S versus M (residence half time in lung greater than 700 days) is seven times greater than for selecting Y versus W in ICRP 30 (half time greater than 100 days) (ICRP, 1995, page 397)

The ICRP 30 clearance classes for plutonium (as well as the choices for ingestion dose conversion factor) were based largely upon the chemical state of the plutonium Y was recommended for oxides and W for all other compounds and mixtures of compounds This system is loosely retained in ICRP 68 (ICRP, 1994b) (workers) reflecting the higher degree of confidence in the chemical and physical characteristics of the inhalation and ingestion exposures in the occupational setting For ICRP 72 (public) (ICRP, 1996) the S, M, and F absorption types are not to be strictly based upon chemical form, unless confidence in the chemical form is high

The agencies differed in their opinions as to the degree of certainty in the chemical and physical form of the plutonium in the environment around Rocky Flats DOE believes that there is high confidence that the plutonium in the environment is present as pure plutonium dioxide, for which the absorption Type S is the appropriate choice The other agencies did not hold such high confidence of complete oxidation of the plutonium released to the environment, and also admitted the possibility of additional confounding factors such as attachment to small soil particles, for which absorption from the lung to the blood may be influenced by the rate of dissolution of the soil matrix as well as the chemical form of the plutonium ICRP 71 (ICRP, 1995b) provides the results of new studies done since the publication of ICRP 30 (ICRP, 1979) This original publication shows greater variability in the absorption behavior of plutonium under environmental (as opposed to workplace) conditions, describes a number of chemical and physical complicating factors, and advocates the selection of Type M, as a measure of prudence, in the absence of site-specific information Although there is site-specific information at Rocky Flats that indicates that plutonium dioxide is present under the 903 Pad, the majority of the working group felt that there was uncertainty in the degree of oxidation across the entire site It was therefore prudent to select Type M for use in dose calculations in this Task All parties agreed, however, that while disagreement remained on the science and on the interpretation of the ICRPs, the calculation of RSALs was effected to only a minor extent and in the direction of greater conservatism

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Table 4-9 Comparative inhalation dose conversion factors (millirem/picoCurie)

Isotope	ICRP 30 Dose Conversion Factors		ICRP 72 Dose Conversion Factors (adult)		ICRP 72 Dose Conversion Factors (child)	
Pu-239/240	W	0 43	M	0 19[2]	M	0 29[2]
	Y	0 31[1]	S	0 06	S	0 14
Am-241	W	0 44[1]	M	0 16[2]	M	0 26[2]
			S	0 06	S	0 15

[1]Value used in 1996
[2]Value used in this report

Table 4-10 Comparative ingestion dose conversion factors (millirem/picoCurie)

Isotope	ICRP 30 Dose Conversion Factors		ICRP 72 Dose Conversion Factors (adult)		ICRP 72 Dose Conversion Factors (child)	
Pu-239/240	Nitrates	0 0035	All forms	0 00093[2]	All forms	0 0016[2]
	All other	0 00037				
	Oxides	0 000052[1]				
Am-241	All forms	0 0036[1]	All forms	0 00074[2]	All forms	0 0014[2]

[1]Value used in 1996
[2]Value used in this report

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5.0 RISK AND DOSE MODELING RESULTS AND DISCUSSION

Chapter 5 summarizes and interprets the results from the risk and the dose-based calculations of RSALs The RESRAD and Standard Risk equations provide estimates of RSALs for individual radionuclides These results are presented in Tables 5-1, 5-5, 5-9, and 5-12 For remediation field application, the RSALs will be applied as sum-of–ratios wherever both plutonium and americium (a predominant decay product) are present together in the environment The approach for calculating sum-of-ratios is discussed in Section 5 1, and the nominal sum-of-ratio values associated with complete americium in-growth in weapons-grade plutonium are shown in Tables 5-2, 5-6, 5-10, and 5-13

5.1 SUM-OF-RATIOS METHODOLOGY FOR MULTIPLE RADIONUCLIDES AND ADJUSTED RSALS FOR AMERICIUM AND PLUTONIUM

If multiple radionuclides are present in the environment, the sum-of-ratios method is typically used to account for the contribution of each single isotope towards the dose- or risk-based limit Measured values of all radionuclides present are compared to action levels by dividing the measured value of each radionuclide by its respective action level, then adding the ratios If the sum of the individual ratios is greater than one, then the limit is exceeded

$$\frac{R1_M}{R1_{AL}} + \frac{R2_M}{R2_{AL}} + \frac{R3_M}{R3_{AL}} + \quad + \frac{Rn_M}{Rn_{AL}} < 1$$

where,

$R1_M$ = measured value of the first radionuclide, etc
$R1_{AL}$ = action level of the first radionuclide, etc

If the proportion of each radionuclide in the soil (activity ratio, ρ) is known, this equation can be modified to develop adjusted RSALs for single radionuclides in that mixture For example, the following equation is used to derive a sum-of-ratios-adjusted action level for plutonium in the presence of americium

$$Pu_{SR} = \frac{Pu_{AL} \times Am_{AL}}{\rho Pu_{AL} + Am_{AL}}$$

where,

Pu_{SR} = sum-of-ratios-adjusted action level for plutonium
Pu_{AL} = action level for plutonium
Am_{AL} = action level for americium
ρ = Am Pu activity ratio

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The sum-of-ratios-adjusted action level for americium can then be calculated as follows

$$Am_{SR} = (1 - \frac{Pu_{SR}}{Pu_{AL}})\ Am_{AL}$$

Whenever presenting RSALs adjusted by sum-of-ratios calculations, it is important that the americium plutonium activity ratio also be specified In this risk assessment, a nominal activity ratio of 0 182 has been used, which corresponds to the value for typical weapons-grade plutonium with maximum in-growth of americium This value is about 20% higher than what is currently found at Rocky Flats near the 903 Pad Tables in the following sections give examples of adjusted RSALs selected from the 5th percentile of the RSAL distributions (see Sections 5 1 and 5 2) calculated by the probabilistic risk and dose approaches

5.2 RISK MODELING RESULTS FOR EACH SCENARIO

The results of the risk-based RSALs are presented for the rural resident (Table 5-1), the wildlife refuge worker (Table 5-5), the office worker (Table 5-9), and open space user (Table 5-12) The RSALs for the rural resident and wildlife refuge worker were estimated using both probabilistic and point estimate approaches All probabilistic simulations are run with 10,000 iterations using Crystal Ball® The RSALs for the office worker and open space user were estimated using only a point estimate approach A probabilistic assessment was not performed for these two exposure scenarios because they are not expected to have a significant impact on the risk decision-making process for this site Since the development of a probabilistic assessment can be very time and resource intensive, the working group made a decision to focus its efforts on developing the probabilistic assessments for the Rural Residential and Wildlife Refuge Worker scenarios For the point estimate approach, single values representing a RME individual were input to the equation and a single RSAL value was calculated for each radionuclide at the target cancer risk levels of 10^{-4}, 10^{-5}, and 10^{-6} As shown in Table 5-9, for example, an RME office worker who is exposed daily to 63 pCi/g of Am-241 in soil over 25 years would have no greater than a 1 in 100,000 chance of developing cancer as a result of that exposure, a 10^{-5} risk Directly below each table showing RSAL estimates for individual radionuclides is a table that presents the RSAL values adjusted by the sum-of-ratios method to account for the additional activity of either americium or plutonium (Tables 5-2, 5-6, 5-10, and 5-13) As shown in Table 5-10, when Am-241 and Pu-239 are considered together, the RSAL for Am-241 in the Office Worker scenario reduces to 12 pCi/g for a target risk of 10^{-5} Additional tables summarize the percent contributions by each exposure pathway considered in the assessment (Tables 5-3, 5-4, 5-7, 5-11, and 5-14) The RSALs are protective for cumulative exposure across all these pathways

The EPA is required by law to use the RME individual as a basis for evaluating human health risks and developing preliminary remediation goals (or RSALs) at Superfund sites (U S EPA, 1990) In a point estimate approach the RSAL represents a soil concentration that is protective of the RME individual In a probabilistic approach, EPA defines the 90th to 99th percentiles of a *risk* distribution as the recommended RME range, with the 95th percentile as the starting point for risk-decision making (U S EPA, 2001b) Because RSAL calculations, for the most part, are the inverse of risk calculations, the RME range for the RSAL distribution corresponds to the 10th to 1st percentiles, with the 5th percentile as the recommended starting point Similar to the point estimate approach, probabilistic RSALs are presented as a range of target cancer-risk levels

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Probabilistic risk-based RSALs are presented in Tables 5-1 and 5-5 for the rural resident and the wildlife refuge worker, respectively A range of values, described as probability distributions, was input to the equations, yielding a range or distribution of RSALs that reflects variability in exposures among a population A health-protective RSAL can be selected from this distribution As an example of how the tables can be used, using the recommended starting point of the 5th percentile, an RME resident exposed over a lifetime (both childhood and adulthood exposure) to 9 pCi/g of Am-241 in soil would have no greater than a 1 in 100,000 (10^{-5}) chance of contracting cancer This is in addition to the background cancer rate of approximately 1 in 3 in the U S (Colorado Central Cancer Registry, 1999)

The probabilistic estimates and the point estimates for individual radionuclides are presented side-by-side in Tables 5-1 and 5-5 for perspective When the estimates are consistent (i e , the point estimate falls within the 10th to 1st percentiles of the probabilistic results there is a tendency to accept the results with an increased level of confidence However, the results are not expected to be identical The two methods represent different concepts about how to estimate risks to the RME individual For example, in the point estimate approach, the parameters are fixed, no matter what the probability of having that specific combination of inputs It would be serendipitous to have those fixed values coincide exactly with a probabilistic assessment of the same scenario at the 90th, 95th, 99th or any other percent confidence levels If the estimates differ significantly, it is important to evaluate the assumptions associated with the inputs to the exposure equations to understand the reasons for the difference This methodological difference is discussed further in Chapter 7

Table 5-1 Risk-based RSALs (probabilistic and point estimate) for individual radionuclides for the rural resident

Radionuclide	Percentile[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
Am-241	10th	145	14 0	1 0
	5th	93	9 0	1 0
	1st	39	4 0	0 4
	Point estimate	70	7 0	1 0
Pu-239	10th	439	44 0	4 0
	5th	284	28 0	3 0
	1st	139	14 0	1 0
	Point estimate	128	13 0	1 0

[1]The lower percentiles (10th to 1st) of the RSAL distribution correspond to upper percentiles (90th to 99th)of the risk distribution These percentile ranges are referred to as the RME range

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Table 5-2 Risk-based RSALs for the rural resident from Table 5-1 adjusted by SOR method

Radionuclide	Percentile of RSAL Distribution[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
Am-241	10th	52	5 0	1 0
	5th	33	3 0	0 3
	1st	15	2 0	0 2
	Point estimate	17	2 0	0 2
Pu-239	10th	283	28 0	3 0
	5th	183	18 0	2 0
	1st	84	9 0	1 0
	Point estimate	96	10 0	1 0

[1]The lower percentiles (10th to 1st) of the RSAL distribution correspond to upper percentiles (90th to 99th) of the risk distribution, which are referred to as the RME range
SOR = sum-of-ratios

Table 5-3 Probabilistic risk-based RSALs for the rural resident – percent (%) contributions of exposure pathways to RSALs using individual nuclides and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu SOR Adjusted (%)
	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	
External	49 3	7 6	1 6	1 4	**9 0**
Inhalation	7 9	1 2	32 4	27 4	**28 6**
Plant ingestion	29 4	4 5	15 9	13 5	**18 0**
Soil ingestion	13 4	2 1	50 1	42 4	**44 5**

[1]The arithmetic mean of the probability distribution of percent contributions of exposure pathways to the RSAL calculated for the individual nuclide
[2]Arithmetic mean percent contribution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

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Table 5-4 Point estimate risk-based RSALs for the rural resident – percent (%) contributions of exposure pathways to RSALs using individual nuclides and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu
	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	SOR Adjusted (%)
External	24 4	3 8	0 3	0 3	**4 1**
Inhalation	18 2	2 8	39 4	33 3	**36 1**
Plant ingestion	38 3	5 9	15 5	13 1	**19 0**
Soil ingestion	19 1	2 9	44 7	37 8	**40 7**

[1]The relative contributions of exposure pathways to the RSAL calculated for the individual nuclide
[2]Relative pathway contribution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

Table 5-5 Risk-based RSALs (probabilistic and point estimate) for individual radionuclides for wildlife refuge worker

Radionuclide	Percentile[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
Am-241	10^{th}	904	90	9 0
	5^{th}	760	76	7 6
	1^{st}	560	56	5 6
	Point estimate	514	51	5 1
Pu-239	10^{th}	1,472	147	14 7
	5^{th}	1,160	116	11 6
	1^{st}	737	74	7 4
	Point estimate	670	67	6 7

[1]The lower percentiles (10^{th} to 1^{st}) of the RSAL distribution correspond to upper percentiles (90^{th} to 99^{th}) of the risk distribution These percentile ranges are referred to as the RME range

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Table 5-6. Risk-based RSALs (probabilistic and point estimate) for the wildlife refuge worker from Table 5-5 adjusted by the SOR method

Radionuclide	Percentile of RSAL Distribution[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
Am-241	10th	207	21	2
	5th	165	17	2
	1st	108	11	1
	Point estimate	99	10	1
Pu-239	10th	1,136	114	11
	5th	908	91	9
	1st	594	59	6
	Point estimate	541	54	5

[1]The lower percentiles (10th to 1st) of the RSAL distribution correspond to upper percentiles (90th to 99th) of the risk distribution, which are referred to as the RME range
SOR = sum-of-ratios

Table 5-7 Probabilistic risk-based RSALs for the wildlife refuge worker – percent (%) contributions of exposure pathways to RSALs using individual nuclides and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu
	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	SOR Adjusted (%)
External	58 2	8 9	0 4	0 8	**9 7**
Inhalation	21 7	3 3	48 9	41 5	**44 8**
Plant ingestion	0 0	0 0	0 0	0 0	**0 0**
Soil ingestion	20 1	3 1	50 1	42 4	**45 5**

[1]The arithmetic mean of the probability distribution of percent contributions of exposure pathways to the RSAL calculated for the individual nuclide
[2]Arithmetic mean percent contribution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

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Table 5-8 Point estimate risk-based RSALs for the wildlife refuge worker – percent (%) contributions of exposure pathways to RSALs using individual nuclides and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu SOR Adjusted (%)
	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	
External	38 2	5 8	0 4	0 3	**6 1**
Inhalation	40 0	6 1	61 8	52 3	**58 4**
Plant ingestion	0 0	0 0	0 0	0 0	**0 0**
Soil ingestion	21 9	3 3	37 9	32 1	**35 4**

[1]The relative contributions of exposure pathways to the RSAL calculated for the individual nuclide
[2]Relative pathway contribution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

Table 5-9 Risk-based RSALs (point estimate only) for individual radionuclides for the office worker

Radionuclide	RSALs (pCi/g) at Selected Target Risks		
	10^{-4}	10^{-5}	10^{-6}
Am-241	634	63	6 3
Pu-239	806	81	8 1

Table 5-10 Risk-based RSALs (point estimate only) for the office worker from Table 5-9 adjusted by the SOR method

Radionuclide	RSALs (pCi/g) at Selected Target Risks		
	10^{-4}	10^{-5}	10^{-6}
Am-241	119	12	1
Pu-239	655	65	7

SOR = sum-of-ratios

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Table 5-11 Pomt estmate nsk-based RSALs for the office worker – percent (%) contnbutions of exposure pathways to RSALs usmg mdividual nuchdes and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu
	Individual Nuchde[1] (%)	SOR Adjusted[2] (%)	Individual Nuchde[1] (%)	SOR Adjusted[2] (%)	SOR Adjusted (%)
External	36 0	5 5	0 3	0 3	**5 7**
Inhalation	46 0	7 0	69 2	58 6	**65.7**
Plant ingestion	0 0	0 0	0 0	0 0	**0 0**
Soil ingestion	18 0	2 7	30 5	25 8	**28 6**

[1]The relative contnbutions of exposure pathways to the RSAL calculated for the mdividual nuchde
[2]Relative pathway contnbution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

Table 5-12 Risk-based RSALs (pomt estimate only) for mdividual radionuchdes for the open space user (pCi/g)

Radionuchde	RSALs (pCi/g) at Selected Target Risks		
	10^{-4}	10^{-5}	10^{-6}
Am-241	1,088	109	10 9
Pu-239	1,143	114	11 4

Table 5-13 Risk-based RSALs (pomt estimate only) for the open space user from Table 5-12 adjusted by the SOR method

Radionuchde	RSALs (pCi/g) at Selected Target Risks		
	10^{-4}	10^{-5}	10^{-6}
Am-241	175	17	2
Pu-239	960	96	10

SOR = sum-of-ratios

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Table 5-14 Point estimate risk-based RSALs for the open space user – percent (%) contributions of exposure pathways to RSALs using individual nuclides and adjusted by SOR method

Exposure Pathway	Americium (Am)		Plutonium (Pu)		Am + Pu SOR Adjusted (%)
	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	Individual Nuclide[1] (%)	SOR Adjusted[2] (%)	
External	23 1	3 5	0 2	0 2	**3 7**
Inhalation	34 4	5 2	42 8	36 3	**41 5**
Plant ingestion	0 0	0 0	0 0	0 0	**0 0**
Soil ingestion	42 5	6 5	57	48 3	**54 8**

[1]The relative contributions of exposure pathways to the RSAL calculated for the individual nuclide
[2]Relative pathway contribution adjusted by SOR method to account for an Am Pu activity ratio of 0 182
SOR = sum-of-ratios

Despite the number of apparent significant digits reported in the tables above, the estimates should not be viewed as exact calculations There are inherent uncertainties in the risk assessment process The selection of future land use scenarios, risk or dose models, and parameter inputs all require careful evaluation of the existing information and an assessment of the strengths and weaknesses of that information These strengths and weaknesses must be communicated to the risk decision-makers to facilitate health-protective remedial decision-making Chapter 7 provides a more detailed discussion regarding the sources of variability and uncertainty in this risk assessment that may have the greatest impact on the selection of an RSAL that is protective of the RME individual As a general practice, the working group tried to present data as accurately and factually as possible without interjecting bias When the information on variability was sparse or otherwise uncertain in the probabilistic approach, the working group employed professional judgment in selecting a probability distribution, or in some cases a health-protective point estimate, with tendency to bias the estimate somewhat conservatively

It is important to understand that RSALs are initial guidelines and do not represent final cleanup or remediation levels Risk managers must evaluate the remedial alternatives against the nine criteria described in the National Contingency Plan (NCP) (U S EPA, 1990) These criteria are given in Table 5-15 Achieving a target level of protection is one of the primary factors, but this objective needs to be balanced by other criteria such as feasibility, permanence, state and community acceptance, and cost A final cleanup level may differ from an RSAL following a comprehensive evaluation of these criteria

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Table 5-15 Nine criteria for evaluation of cleanup alternatives [1]

Category		Criteria
Threshold criteria	1	Overall protection of human health and the environment
	2	Compliance with applicable or relevant and appropriate requirements (ARARs)
Balancing criteria	3	Long-term effectiveness and permanence
	4	Reduction in toxicity, mobility, or volume through treatment
	5	Short-term effectiveness
	6	Implementability
	7	Cost
Modifying criteria	8	State acceptance
	9	Community acceptance

[1]Source National Contingency Plan, U S EPA, 1990

5.3 DOSE-BASED RSALS FOR INDIVIDUAL RADIONUCLIDES

The results of the dose-based calculations are expressed in terms of individual radionuclide surface-soil activity concentrations that equate to a 25-mrem annual dose The RSAL values for individual radionuclides as well as the adjusted sum-of-ratio values are shown in Tables 5-16, 5-17, 5-18, 5-20, 5-22, 5-23, and 5-24 The calculations are based on RESRAD 6 0 simulations for the following potential receptor populations rural resident adult and child, wildlife refuge worker, office worker, and open space user RSALs for probabilistic calculations have been selected at the 5th percentile of the probability distribution

Table 5-16 Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by the SOR method for the adult rural resident

Radionuclide	Percentile of Dose Distribution[1]	Annual Dose (mrem/yr per 100 pCi/g)	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)
Am-241	50th	6 02	414	141
	90th	22 1	113	59
	95th	34 8	71 9	42
	Point estimate	11 2	191	56
Pu-239	50th	2 14	1,168	772
	90th	3 65	685	326
	95th	4 48	558	231
	Point estimate	2 32	433	307

[1]The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed earlier in this chapter For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate annual dose is the arithmetic mean
SOR = sum-of-ratios

Table 5-17 Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by the SOR method for the child rural resident

Radionuclide	Percentile of Dose Distribution[1]	Annual Dose (mrem/yr per 100 pCi/g)	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)
Am-241	50th	4 05	617	237
	90th	9 53	262	69
	95th	12 3	203	46
	Point estimate	5 26	137	29
Pu-239	50th	1 18	2,119	1,304
	90th	4 85	515	379
	95th	7 71	324	251
	Point estimate	2 29	205	161

[1]The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed earlier in this chapter For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate annual dose is the arithmetic mean
SOR = sum-of-ratios

Table 5-18. Percent (%) contributions of exposure pathways to probabilistic dose-based RSALs for the rural resident adjusted by SOR method [1]

Exposure Pathway	Am + Pu SOR Adjusted (%)	
	Adult	**Child**
External	**3 3**	**3 0**
Inhalation	**10 9**	**10 0**
Plant ingestion	**40 1**	**18 0**
Soil ingestion	**45 0**	**69 0**

[1]Estimated using the 5th percentile dose-based RSAL
SOR = sum-of-ratios

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Table 5-19. Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by SOR method for the Wildlife Refuge Worker scenario

Radionuclide	Percentile of Dose Distribution[1]	Annual Dose (mrem/yr per 100 pCi/g)	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)
Am-241	50th	1 65	1,515	253
	90th	2 44	1,025	150
	95th	2 55	980	142
	Point estimate	1 66	941	139
Pu-239	50th	1 5	1,667	1,389
	90th	2 6	962	822
	95th	2 74	912	780
	Point estimate	1 51	898	765

[1]The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed earlier in this chapter For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate annual dose is the arithmetic mean
SOR = sum-of-ratios

Table 5-20 Percent (%) contributions of exposure pathways to probabilistic dose-based RSALs for the wildlife refuge worker adjusted by SOR method [1]

Exposure Pathway	Am + Pu SOR Adjusted (%) (Adult)
External	**3 7**
Inhalation	**16 1**
Plant ingestion	**0 0**
Soil ingestion	**80 3**

[1]Estimated using the 5th percentile dose-based RSAL
SOR = sum-of-ratios

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Table 5-21 Point estimate dose-based RSALs for individual radionuclides and adjusted by SOR method for the office worker

Radionuclide	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)
Am-241	1,890	291
Pu-239	1,889	1,598

SOR = sum-of-ratios

Table 5-22 Percent (%) contributions of exposure pathways to point estimate dose-based RSALs for the office worker adjusted by SOR method

Exposure Pathway	Am + Pu SOR Adjusted (%) (Adult)
External	**4 4**
Inhalation	**11 0**
Plant ingestion	**0 0**
Soil ingestion	**84 6**

SOR = sum-of-ratios

Table 5-23 Point estimate dose-based RSALs (pCi/g) for individual radionuclides and adjusted by SOR method for the open space user

Radionuclide	Adult		Child	
	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)	Individual RSAL (pCi/g)	Sum-of-Ratios RSAL (pCi/g)
Am-241	4,556	658	1,621	219
Pu-239	4,228	3,617	1,394	1,205

SOR = sum-of-ratios

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Table 5-24 Percent (%) contributions of exposure pathways to point estimate dose-based RSALs for the open space user adjusted by SOR method

Exposure Pathway	Am + Pu SOR Adjusted (%)	
	Adult	Child
External	3 3	1 1
Inhalation	16 8	6 2
Plant ingestion	0 0	0 0
Soil ingestion	79 9	92 7

SOR = sum-of-ratios

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6.0 RSALs FOR URANIUM CONTAMINATION AT ROCKY FLATS USING RESRAD 6.0 AND EPA STANDARD RISK EQUATIONS

6.1 INTRODUCTION

Uranium contamination at Rocky Flats is primarily present as subsurface "hot spots" of relatively small areas of uncertain extent To address this conservatively, the working group elected to model a hypothetical area of surface contamination both large enough (five acres) and deep enough (50 cm) to assure pathway saturation for all principle pathways for the Rural Resident and Wildlife Refuge Worker scenarios Since a relatively broad range of ratios of uranium isotopes have been used at Rocky Flats, the working group performed the RSAL calculations for the two bounding situations (depleted uranium and 20% enriched uranium) and proposed the RSAL that is most restrictive to assure adequate protection with a single criterion Other RSAL selections are possible based on the site-specific mix of uranium isotopes Toxicity of uranium to the human kidney necessitated the application of a test to assure that the RSAL would be adequately protective in the scenarios modeled Most of the parameters for the computations, and all of the scenarios, are the same for uranium as for the plutonium and americium calculations The principle exception is the use of a lognormal distribution for the plant uptake fraction for uranium, which is observed to be quite variable, and influenced by a number of factors such as soil type, plant species type, weather, etc The principal pathway for the Rural Resident scenario is the plant ingestion pathway, which contributes 50 to 90% of the dose For the wildlife refuge worker, the principal pathway is the external exposure pathway In both cases the single criterion for enriched uranium (31 µg/g, total uranium for the adult resident, and 225 µg/g, total uranium for the wildlife refuge worker for the RESRAD dose based computations) proved to be adequately protective both radiologically and toxicologically Since these criteria were computed using very conservative modeling assumptions (large area of surface contamination) compared to the actual situations to be encountered (small area "hot spots" of primarily subsurface contamination), the use of "hot spot" criteria could be considered, to give a more realistic, although still conservative clean-up level

6.2 DESCRIPTION OF PROBLEM RELATED TO URANIUM CONTAMINATION

The problem of uranium contamination at Rocky Flats is fundamentally different from the problem of plutonium and americium contamination Based upon the information that the working group had available, the differences may be summarized as follows

- Uranium contamination occurs in a number of isolated spots at known locations on the site where processing or disposal activities took place The actual areas of the spots (within solar ponds, burn pits, trenches, etc) are uncertain but estimated to be less than 100 m^2 per spot

- With few exceptions, all of the uranium contamination on site is subsurface contamination, covered by uncontaminated soil Subsurface characterization data are limited

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- Two distinct types of uranium were processed at Rocky Flats depleted uranium, and enriched uranium (presumably of varying degrees of enrichment) Disposal activities of each type appear to have been conducted in different locations, with the possibility of a few locations where both types are present

For the dose- and risk-based calculations of RSALs, the working group decided to exclude groundwater dependent pathways for the scenarios modeled (i e , Wildlife Refuge Worker, Rural Resident Adult, and Rural Resident Child) The decision to suppress groundwater dependent pathways was based upon the premise that the available shallow groundwater is insufficient in both quality and quantity to supply a resident, and would not be used by a refuge worker

In the absence of groundwater pathways, the current situation of buried contamination in small isolated "hot spots" presents only incidental exposure routes to either residents or refuge workers, unless the contaminated material is brought to the surface In that case the material would constitute an exposure hazard to either an adult or child rural resident through the same four pathways considered (external exposure, inhalation, home-grown plant ingestion, and soil ingestion) The wildlife refuge worker would also be exposed to the same three pathways (external exposure, inhalation, and soil ingestion) as described in the assessment for plutonium and americium

6.3 APPROACH

The RSALs for uranium were calculated in much the same manner as for plutonium and americium Since the development of a probabilistic assessment is time and resource intensive, the working group decided to focus its efforts on developing probabilistic uranium RSALs for the Rural Resident and Wildlife Refuge Worker scenarios For both the dose and risk approaches, point estimates were also calculated using values representative of the RME individual An assessment was not done on the Office Worker and Open Space User scenarios for the uranium case The same exposure pathways and exposure assumptions used for plutonium and americium RSALs were used for uranium, except as noted below

- Additional Pathway and Parameter Sensitivity Studies
- Area and Depth of Contaminated Zone
- Variability of Isotopic Ratios
- Addition of Non-Cancer Toxicity Assessment
- Plant Transfer Factor
- Dose Conversion Factors

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6.4 ADDITIONAL PATHWAY AND PARAMETER SENSITIVITY STUDIES

RESRAD runs were done using an Adult Rural Resident scenario (external, inhalation, soil and plant ingestion pathways active) Single isotope RSALs were calculated for each of the three isotopes using ICRP 72 dose conversion factors (ICRP, 1996) (Type M for inhalation), and varying the area of the contaminated zone between 100 and 40,000 m^2 In addition, the depth of contamination was varied between 1 and 100 cm to observe the effect on the external gamma exposure component (Since the RSAL for this problem is calculated for a hypothetical situation of large area, the working group felt it was also important to set the depth of contamination at an interval from the surface down to where subsurface contamination no longer contributes measurably to external gamma exposure) The majority of RESRAD parameters at this level of investigation were default values The following were observed

- Model year one gives the lowest RSALs using the default erosion rate and hydrological parameters

- For U-238 and U-235, the external exposure pathway dominates (60 to 98% of dose in first year), with the plant ingestion pathway making up essentially the rest

- The depth of contamination affects the surface exposure rate up to approximately 40 cm Deeper levels of subsurface contamination are effectively shielded and do not contribute to the external gamma or any other water independent pathway The working group decided to perform all future uranium calculations using an interval of 0 to 50 cm (to be conservative) for hypothetical depth of contamination This depth of contamination differs from the 0 to15 cm interval used to evaluate plutonium and americium

- For U-234, the plant ingestion pathway dominates (80 to 90%) throughout the time frame, followed by soil ingestion (10%) and inhalation (7%)

- When the plant ingestion pathway is significant, it is sensitive to the area of the contaminated zone in the range tested (sufficient garden areas are required to grow contaminated produce) However, the external gamma pathway is saturated at small areas, on the order of 300 m^2

Table 6-1 Sensitivity analysis results investigating the effect of area of contamination on single isotope potential RSALs (pCi/g)

Isotope	100 m^2	1,000 m^2	40,000 m^2
U-238	455	246	237
U-235	85	66	65
U-234	4,927	527	526

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If only U-238 and U-235 were considered for small "hot spots", external exposure would completely dominate the predicted dose, with plant ingestion making a relatively small contribution. For U-234, the plant ingestion pathway would dominate, implying that plant ingestion becomes more important with a uranium mix having significant U-234, such as enriched uranium. With the possibility of calculating RSALs for larger areas, and considering the variability of the soil-to-plant transfer factor, the importance of the plant ingestion pathway also increases.

The analysis above suggests that the isotopic mix for uranium should be considered when establishing pathway and parameter sensitivity, since the constraints of the isotopic mix significantly affect the relative importance of the plant ingestion and external exposure pathways. The next series of calculations were performed using isotopic ratios associated with depleted uranium (depleted uranium – activity ratios of U-238:U-235:U-234 = 70:1:29), and 20% enriched uranium by weight (enriched uranium – activity ratios 4:6:90). The pathway contributions to total dose are displayed in Table 6-2 for large (40,000 m^2) and small (100 m^2) areas. For all calculations the thickness of the contaminated zone is 0.5 m, the gamma-shielding factor is 0.4, and the plant transfer factor is 0.02. Note that the plant transfer factor used for sensitivity analysis is almost 10 times higher than the RESRAD default.

Table 6-2 Sensitivity analysis to evaluate the relative contributions (%) of exposure pathways to dose calculations for the rural resident

Exposure Pathway	Depleted Uranium (DU)		Enriched Uranium (EU)	
	100 m^2	40,000 m^2	100 m^2	40,000 m^2
Plant ingestion	30.1	76.0	44.3	84.5
External	68.4	20.9	53.4	12.0
Soil ingestion	1.2	2.9	1.7	3.2
Inhalation	0.4	0.2	0.6	0.2

The following factors contribute to the relatively high percent contributions of the plant ingestion pathway for uranium:

- The plant transfer factor has been increased by a factor of two over what was previously modeled.
- There is a significant contribution to the plant ingestion pathway when using realistic combinations of all three isotopes, particularly U-234, which contributes to ingestion pathways but not to external exposure pathways.
- The gamma-shielding has been reduced to 0.4 (the current default value for the *Soil Screening Guidance for Radionuclides: User's Guide,* U.S. EPA, 2000). The RESRAD default is 0.7. The EPA value is more appropriate for uranium.
- Areas large enough to saturate the plant ingestion pathway are being considered.

The relatively high percent contribution of the plant ingestion pathway underscores the importance of developing reliable inputs for the exposure and toxicity variables associated with plant ingestion. Consistent with the approach used for the plutonium and americium RSAL calculations, the working group used the same probability distributions for plant (vegetable, fruit, and grain) ingestion rate and mass loading, which contributes to foliar deposition. In addition, a literature review was conducted to characterize variability in the soil-to-plant transfer factor for uranium. This investigation resulted in the selection of a lognormal distribution for the transfer factor having a 95th percentile value of 0.00645 (a factor of 2.6 times higher than the RESRAD default value, see Section 6.8 and Appendix A).

The soil ingestion pathway is addressed by using the same distributions for adult resident, child resident, and wildlife refuge worker that were used to calculate RSALs for plutonium and americium. Variability in adult soil ingestion rate is characterized by a uniform distribution (all values within a specified range have equal probability) with a minimum value of 0 and maximum of 130 mg/day for adults. Soil ingestion is assumed to occur over a 24-hour period for each day that the adult resident is on the site, and over an 8-hour workday for each day the wildlife refuge worker is on the site. For RESRAD, which expresses inputs as continuous annual average values (i.e., 24 hours per day, 365 days per year), the parameters were converted from units of mg/day to g/yr. For the rural resident, the corresponding uniform probability distribution has a range of (0, 47.45), where the maximum equals 130 mg/day x 365 days/yr x 10^{-3} g/mg = 47.45 g/yr. Similarly, for the wildlife refuge worker, the equivalent ingestion rate is expressed as a uniform distribution with a minimum of 0 g/yr and a maximum of 142.35/yr (130 g/day x 365 days/yr x 10^{-3} g/mg x 24 hrs/8 hrs).

To summarize the sensitivity analysis, the working group has concluded that the exposure model for uranium should include the same set of point estimates and probability distributions as the model for Pu and Am. The only differences with the uranium assessment are the following:

- Use of a hypothetical five acre contaminated zone,
- Use of 0 to 50 cm for depth of the contaminated zone as opposed to 0 to 15 cm for the plutonium and americium calculations, and
- The introduction of a distribution for the plant uptake fraction for uranium.

6.5 AREA AND DEPTH OF CONTAMINATED ZONE

A fundamental difference between the uranium situation and the plutonium situation, assuming that the buried uranium is moved to the surface, is that the area of surface contamination would be much smaller and more uncertain in extent than that of the current plutonium contamination on the site. Although the sensitivity analysis for plutonium and americium suggests that the area of the contaminated zone is not a sensitive variable over the ranges considered appropriate for plutonium (acres to hundreds of acres range), results for uranium over areas typical of "hot spots" shows that in the range from 1 to 100 m^2 it is highly sensitive, and from 100 to 1,000 m^2 it is moderately sensitive. Some of the more important pathways (plant ingestion and external exposure) are not saturated when the area of contamination is small. This is easy to understand for the most significant pathway for residential exposure to uranium—the plant ingestion pathway. To supply a residential family with homegrown food sufficient to provide the majority

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(or all) of their fruit and vegetable intake for year-long periods, a sizable garden is required, on the order of 1,000 to 2,000 m^2 If only a small area of this garden is contaminated because of a small "hot spot", then a correspondingly small fraction of the dietary intake is contaminated—and this will significantly impact the calculation of soil concentrations that meet the target dose or risk

Faced with the two sources of uncertainty—the potential for subsurface contamination to reach the surface from small buried sources, and the areal extent of such surface contamination—the working group chose to address this problem by developing an RSAL for a hypothetical situation of a large area of surface contamination The working group believes that the approach of modeling a hypothetical large area as a surrogate for a much smaller real area of uncertain size is very conservative The area of contaminated zone ultimately selected by the working group was five acres

6.6 VARIABILITY OF ISOTOPIC RATIOS

A second way in which the uranium calculation differs from the plutonium calculation has to do with the presence of both depleted uranium and enriched uranium at Rocky Flats The isotopic mix of the three uranium isotopes (mass numbers 238, 235, and 234) strongly influences the sum-of-ratio adjusted RSALs For this reason, the working group decided to compute the single radionuclide RSALs using a probabilistic approach with RESRAD 6 0 and the Standard Risk equations, for each of the three isotopes for each scenario Separate sum-of-ratios RSALs are presented for the case of depleted uranium and enriched uranium For the degree of enrichment (of U-235 by weight), the working group chose 20%, since the isotopic activity ratios of the three isotopes remain fairly constant above this enrichment

6.7 ADDITION OF NON-CANCER TOXICITY ASSESSMENT

For uranium, there is an additional consideration of chemical toxicity Depending on the isotopic mix of the three principle uranium isotopes (see below), and the resulting activity per unit mass of the resulting mixture, compliance with the radiologically based protective criteria may not be sufficiently protective to assure that the resident would not exceed the safe limit of daily intake of uranium from ingestion of plants and soil (the two ingestion pathways) This safe limit, referred to as the Reference Dose (RfD), was taken from the Superfund Integrated Risk Information System (IRIS), and represents an average-daily intake, which if taken over a long period of time provides adequate assurance of no chronic-adverse effects on the human kidney (proteinuria) The RfD for uranium is 3 0 µg/day/kg of body weight Consideration of the chemical toxicity in addition to the radiological protective criterion necessitates that an additional test be made on the calculated RSAL quantities This test requires that the internal exposure (inhalation and ingestion) components of the modeled annual dose (25 mrem) do not result in average-daily intakes exceeding the RfD If the RfD is exceeded in either the case of depleted or enriched uranium, then additional reductions must be applied to one or both RSALs This reduction assures that the soil-action level does not result in potential average-daily intakes that exceed the RfD throughout the range of isotopic mixtures considered

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6.8 DETERMINATION OF SOIL-TO-PLANT TRANSFER FACTORS FOR URANIUM

The soil-to-plant transfer factor (TF) is defined as the concentration of isotope in the plant tissue divided by the concentration in the soil The RESRAD default value for uranium is 0 0025 According to a cursory literature review on plant uptake of uranium provided by DOE, it appears that there is high variability in this term ranging from approximately 0 001 to 0 1 with an extreme value of 3 3 at a uranium-milling site Numerous factors may interact in a complex manner to control the availability of uranium in surface soil, and the uptake and translocation of uranium by plants Several of these factors are shown Table 6-3

Table 6-3 Factors that is likely to contribute to variability in soil-to-plant transfer factors for uranium

Factor	Effect on Soil-to-Plant Transfer Factor (TF)
Soil pH, carbonate content	High pH and low carbonate content tends to increase transfer factor, but effects will vary by plant
Soil phosphorus	High P levels tend to decrease transfer factor
Organic matter	Uranium mobility is reduced in higher organic matter soils, resulting in lower plant uptake and lower transfer factor, values for organic soils are 4- to 40-fold lower than mineral soils
Soil texture (clay/silt/sand)	Uranium mobility is reduced in finer textured soils (clay), resulting in lower plant uptake and lower transfer factor
Chemical form	Predominant chemical species of uranium in soil is cationic, specifically the uranyl ion, $UO^{2+}{}_2$, transfer factor values are lower in soils with higher cation exchange capacity (e g , clay)
Uranium concentration	Transfer factor values tend to decrease as concentrations in substrate (soil) increase, this may reflect, in part, the decreasing fractions of bioavailable uranium in soil as total uranium increases Transfer factor is really a direct measure of uranium available to the plant, rather than total uranium in the soil matrix
Plant type and part	Root crops tend to have higher transfer factor values than leafy vegetables or grains due to adsorption to cell walls, uncertainty stems from numerous sources of variability among plant types some plants can alter the microenvironment (e g , pH, Eh, solubility) within the bulk soil by exuding specific enzymes and chelates, metabolic byproducts, and waste inorganic materials

There was a concern that the default value in RESRAD did not reflect the variability in transfer factor that could occur at the Rocky Flats site A more extensive review of the existing literature was conducted, looking at uptake of uranium into different types of plants under a variety of soil conditions From those studies, a single distribution was developed which was applicable for a mixture of soil types including clays, sandy soil, and areas of high organic content A combined distribution was considered appropriate because all of these soil types are present at the Rocky Flats site This probability distribution is shown in Table 6-4 A more detailed description of the

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studies reviewed, the plant and soil types evaluated, and the development of the probability distribution is provided in Appendix A (A 1 5)

Table 6-4 Probability distribution for uranium soil-to-plant transfer factor (unitless)

Lognormal Distribution Parameters[3]	Wet Weight[1]	Dry Weight[2]			
	All Food Groups	All Food Groups	Leafy Vegetables	Fruit, Root Vegetables	Cereals
AM	0 0019	0 0155	0 0206	0 0077	0 0068
SD	0 0029	0 0233	0 0209	0 0155	0 0046
95th %tile	0 0064	0 0512	0 0576	0 0278	0 0155
GM	0 0011	0 0085	0 0144	0 0034	0 0056
GSD	2 97	2 97	2 32	3 57	1 86
AM of ln(x)	-6 8355	-4 7633	-4 2392	-5 6727	-5 1876
SD of ln(x)	1 0893	1 0893	0 8420	1 2712	0 6199

[1]Wet Weight units for RESRAD model runs
[2]Dry weight units for Standard Risk equations
[3]Parameters arithmetic mean (AM), standard deviation (SD), geometric mean (GM), geometric standard deviation (GSD), percentile (%ile), natural logarithm of X (ln(x))

6.9 SELECTION OF DOSE CONVERSION FACTORS FOR URANIUM

Consistent with the approach used by the working group for plutonium and americium, dose conversion factors for uranium were selected from ICRP 72 (ICRP, 1996), as opposed to ICRP 30 (ICRP, 1979) As been discussed, this is justified on the basis of more detailed and refined biokinetic models, is specifically applicable to members of the public as opposed to radiation workers, and incorporates the results of more recent human and animal research The salient features of the selection process are as follows

- ICRP 72 (ICRP, 1996) (Dose Conversion Factor's for Members of the Public) dose conversion factors for uranium were used in this assessment The dose conversion factors used in this assessment are shown in bold in Table 6-5 below ICRP 72 lists only one choice for **ingestion** dose conversion factor for each uranium isotope (Age specific—different values for age categories 3 months, 1 year, 5 year, 10 years, 15 years, and adult) The ingestion dose conversion factor's that were used in these calculations are for the adult and one-year old child (consistent with the plutonium and americium calculations)

- ICRP 72 (ICRP, 1996) lists three choices (F, M, and S) based on fast medium and slow absorption from the lung to the blood for **inhalation** dose conversion factor's for each uranium isotope (age specific as above) The most conservative dose conversion factor's for all uranium isotopes (i e , highest dose per picoCurie inhaled) are those of the S Absorption Type Per ICRP 71 guidance (ICRP, 1995), chemical form alone is not to be used as a sole basis for selection of absorption type in the case of environmental exposure The studies cited for animals suggest that UO_2 behaves as Type S, other

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uranium oxides (e g , UO_3, U_3O_8) show variability between Types M and S, and most other compounds show variability between Types M and F This assessment followed the recommendation from ICRP that the default Type in the absence of site-specific information is Type M

- Although there is a significant difference in the value of dose conversion factor between the M and the S Absorption Types for each uranium isotope, there is very little impact on dose calculations using RESRAD Typically, most of the dose computed in residential scenarios is due to external gamma exposure and plant ingestion, with a relatively small fraction due to inhalation

Table 6-5 ICRP 72 dose conversion factors (DCF) for uranium (values in bold were used in these calculations) (ICRP, 1996)

Isotope	DCF Type	DCF Adult (mrem/pCi)	DCF Child, Age 1 (mrem/pCi)
U-238	**Ingestion**	**0 00165**	**0 00044**
	Inhalation (M)	**0 0106**	**0 0344**
	Inhalation (S)	0 03	0 0938
U-235	**Ingestion**	**0 00172**	**0 000475**
	Inhalation (M)	**0 011**	**0 0355**
	Inhalation (S)	0 031	0 0948
U-234	**Ingestion**	**0 00018**	**0 000478**
	Inhalation (M)	**0 013**	**0 0409**
	Inhalation (S)	0 035	0 108

6.10 MASS AND ACTIVITY RELATIONSHIPS OF URANIUM

Because of the variability of isotopic ratios discussed above, it is important to distinguish among the percentages of each uranium isotope by weight and by activity Table 6-6 was constructed from Table 2-1 and Figure 2-1 given in the DOE Publication *"Health Physics Manual of Good Practices for Uranium Facilities"* (Bryce et al , 1988)

One of the striking points that can be seen is the amount of U-234 activity present in enriched uranium This is because it concentrates faster than U-235 in the gaseous-diffusion enrichment process (which favors lighter isotopes), and because its half-life is much shorter than the other two isotopes (activity per gram is much higher, or inversely, grams per unit of activity are much lower)

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Table 6-6 Weight and activity relationships for depleted and 20% enriched uranium

Isotope	DU Weight %	EU Weight %	DU Activity %	EU Activity %
U-238	99 75	79 95 (est)	70 0	4 0
U-235	0 25	20 0	1 0	6 0
U-234	0 0005	0 05 (est)	29 0	90 0

DU = depleted uranium, EU = enriched uranium

An empirical formula from the *Practices Manual* (Bryce et al , 1988) relates specific activity to degree of enrichment

$$S = (0\ 4 + 0\ 38E + 0\ 0034E^2) \times 10^{-6}\ \mathrm{Ci/g},\ \text{where } E = \text{percent enrichment}$$

The specific activity for depleted uranium (0 2% U-235) is 4×10^{-7} Ci/g and for 20% enriched uranium it is 9×10^{-6} Ci/g The conversion factors from total activity (pCi) to mass (micrograms or µg) are therefore

Depleted U 1 pCi = 2 5 µg, or 1 µg = 0 4 pCi
Enriched U 1 pCi = 0 111 µg or 1 µg = 9 pCi

The expression of total uranium activity of a mix of all three isotopes in terms of mass units is often referred to as "total uranium"

These factors were used to convert total activity of the three isotopes in a given mix to mass in micrograms, and to check whether the toxicity based limit (i e , the RfD) is exceeded for the uptakes (in pCi) associated with the dose and risk calculations

6.11 Dose Computation Procedure

For each scenario a separate RESRAD 6 0 run was performed using 1,000 observations for each of the three uranium isotopes, initially present at 100 pCi/g From the dose distribution table the total dose from uniform contamination of 100 pCi/g corresponding to 95% cumulative probability was selected for the year of maximum dose (year 0 in all cases) This dose was used to scale the single radionuclide soil concentration to that which would result in 25 mrem annual dose This value is expressed as the individual nuclide RSAL in Tables 6-7, 6-8, and 6-9 Following this, the sum-of-ratios RSALs for depleted uranium (70 1 29 isotopic ratios) and 20% enriched uranium (4 6 90 ratios) were calculated for each scenario, and also presented in Tables 6-7, 6-8, and 6-9 This run was also used to establish the fraction of the total dose of 25 mrem that was attributable to ingestion (combined soil and plant ingestion), for comparison with the toxicity RfD The inhalation component was ignored in this calculation since the inhalation contributions for both scenarios were less than 1% of the total dose The ingestion component (expressed as mrem/yr) was converted to daily intake, expressed in µg/kg-day This component is calculated by dividing the mrem/yr ingestion component by the average ingestion dose conversion factor of 0 00017 mrem/pCi for adults or 0 00044 mrem/pCi for children, (from Table 6-5), multiplying that result by the appropriate conversion factor for depleted uranium or

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enriched uranium in µg/pCi, and converting the result to an average daily intake for a 70-kg adult or a 15-kg child) These results are presented in Tables 6-7, 6-8, and 6-9 as well The average daily intake per kg of body weight is converted from the annual-mass intake by dividing by the number of exposure days per year for a RME individual (350 for a resident, 250 for a wildlife refuge worker) and dividing this result by 70 kg for an adult, or 15 kg for a child

6.12 Dose Modeling Results by Scenario

The dose modeling results for each scenario are presented in the following tables

Table 6-7 Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by SOR method for the Adult Rural Resident scenario

Radionuclide	Percentile[1]	Annual Dose (mrem/yr per 100 pCi/g)	RSAL (pCi/g)		
			Individual Nuclide[2]	SOR Adjusted DU[3]	SOR Adjusted EU[4]
U-238	50th	5 26	475	327	27
	90th	8 01	312	249	18
	95th	11 0	227	173	11 3
	Point estimate	6 37	221	221	14 6
U-235	50th	25 6	98	6	61
	90th	30 2	83	3 6	27
	95th	33 2	75	2 5	17
	Point estimate	26 4	65 7	3 2	22
U-234	50th	0 775	3,225	174	923
	90th	3 82	654	103	404
	95th	7 14	350	72	254
	Point estimate	2 13	526	91	328
% of Dose Due to Ingestion				55%	71 6%
Average Daily Intake (µg/kg-day)				8 25	0 5

[1]The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed in Chapter 5 For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate Annual Dose is the arithmetic mean
[2]The dose from each radionuclide that would result in a 25 mrem annual dose
[3]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29 for U-238 U-235 U-234
[4]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90 for U-238 U-235 U-234
DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

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Table 6-8 Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by SOR method for the Child Rural Resident scenario

Radionuclide	Percentile[1]	Annual Dose (mrem/yr per 100 pCi/g)	RSAL (pCi/g)		
			Individual Nuclide[2]	SOR Adjusted DU[3]	SOR Adjusted EU[4]
U-238	50th	5 09	491	426	38
	90th	7 73	323	255	17 7
	95th	9 83	254	194	12 6
	Point estimate	5 86	118	86	5 2
U-235	50th	25 5	98	6 1	57
	90th	29 9	84	3 6	27
	95th	31 9	78 4	2 8	19
	Point estimate	25 9	50	1 2	7 8
U-234	50th	1 01	2,475	176	851
	90th	3 94	635	106	399
	95th	6 23	401	80	284
	Point estimate	1 93	147	36	117
% of Dose Due to Ingestion				70 0%	71 6%
Average Daily Intake (μg/kg-day)				16 7	0 74

[1]The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed in Chapter 5 For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate Annual Dose is the arithmetic mean
[2]The dose from each radionuclide that would result in a 25 mrem annual dose
[3]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29 for U-238 U-235 U-234
[4]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90 for U-238 U-235 U-234
DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

Table 6-9. Dose-based RSALs (probabilistic and point estimate) for individual radionuclides and adjusted by SOR method for the Wildlife Refuge Worker scenario

Radionuclide	Percentile[1]	Annual Dose (mrem/yr per 100 pCi/g)[2]	RSAL (pCi/g) Individual Nuclide[2]	RSAL (pCi/g) SOR Adjusted DU[3]	RSAL (pCi/g) SOR Adjusted EU[4]
U-238	50th	2 11	1,185	1,053	104
	90th	2 33	1,073	930	84
	95th	2 36	1,059	915	81
	Point estimate	2 11	1,004	876	81
U-235	50th	10 6	236	15	156
	90th	11 1	225	13	126
	95th	11 3	221	13	122
	Point estimate	10 6	210	13	121
U-234	50th	0 271	9,225	436	2,330
	90th	0 481	5,198	385	1,886
	95th	0 510	4,902	379	1,826
	Point estimate	0 273	5,307	363	1,818
% of Dose Due to Ingestion				14 7%	35 7%
Average Daily Intake (µg/kg-day)				3 1	0 3

[1] The percentile values for dose-based results can be interpreted similarly to the risk-based results discussed in Chapter 5 For example, the 90th and 95th percentiles of the dose distribution correspond to the 10th and 5th percentiles of the RSAL distribution The point estimate Annual Dose is the arithmetic mean
[2]The dose from each radionuclide that would result in a 25-mrem annual dose
[3]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29 for U-238 U-235 U-234
[4]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90 for U-238 U-235 U-234
DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

The final step in the computation of the RSAL for uranium involves the proposal of a single value, in µg/g, of the toxicity adjusted values for either depleted or enriched uranium, whichever is most restrictive The specification of total uranium by mass (µg/g) instead of specific activity (pCi/g) is a useful convention that allows a single protective criterion to be specified for uranium that is independent of the isotopic mixture, allowing it to be more easily measured in field samples As shown in Table 6-10, the sum-of-ratios RSAL values for depleted uranium and enriched uranium can be expressed as total uranium in micrograms per gram of soil This calculation was performed only for the 5th percentile RSAL values for the depleted uranium and enriched uranium case

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Table 6-10 Dose-based RSALs for depleted uranium and enriched uranium adjusted by SOR method and expressed as total uranium by mass (µg/g)

Scenario	SOR Adjusted RSAL (µg/g)	
	DU	EU
Adult Resident	619	31
Child Resident	692	35
Wildlife Refuge Worker	3,268	225

DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

The 5th percentile RSAL (the 95th percentile of the dose distribution) for both depleted uranium and enriched uranium was converted to a mass basis by dividing the mrem/yr ingestion component by the average ingestion dose conversion factor of 0 00017 mrem/pCi for adults or 0 0004 mrem/pCi for children, and then multiplying that result by the appropriate conversion factor for depleted uranium or enriched uranium in µg/pCi This value was then scaled to an average daily intake for a 70-kg adult or a 15-kg child

In all scenarios, when the depleted uranium RSALs is converted to units of µg/g, and body weight is accounted for, they exceed the RfD for toxicity Table 6-11 gives the results when RSALs are scaled to values that do not exceed the RfD Average daily intake per kg body weight is scaled from the annual mass intake by dividing by the exposure frequency (350 days/yr for a rural resident, 250 days/yr for a wildlife refuge worker), and dividing this result by body weight (70 kg for an adult or 15 kg for a child)

Table 6-11 Dose-based RSALs for depleted uranium and enriched uranium adjusted by sum-of-ratios method, expressed as total uranium by mass (µg/g) and scaled by body weight to values that do not exceed the RfD

Scenario	SOR Adjusted RSAL (µg/g)	
	DU	EU
Adult Resident	225	31
Child Resident	124	35
Wildlife Refuge Worker	3,163	225

DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

The most restrictive adult residential dose-based RSAL for total uranium is associated with enriched uranium The value of 31 µg/g for this RSAL is above the range of normal background levels for uranium Normal background uranium is usually in a natural isotopic ratio that is very different than that of enriched uranium The plant ingestion pathway is the greatest contributor to dose for residents This is primarily due to the use of broad distributions for leafy and non-leafy plant ingestion rates and the broad distribution for the uranium plant transfer factor In the presence of institutional controls, the most restrictive wildlife refuge worker dose-based RSAL is for enriched uranium at 225 µg/g

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6.13 RISK MODELING RESULTS BY SCENARIO

The results of the risk-based RSAL calculations for individual radionuclides are presented for the rural resident in Table 6-12, and the wildlife refuge worker in Table 6-18 The risk-based RSALs for the rural resident and wildlife refuge worker were estimated using both a probabilistic and a point estimate approach For the point estimate approach, single values representing a RME individual were input to the equation and a single RSAL value was calculated for each radionuclide at the target cancer risk levels of 10^{-4}, 10^{-5}, and 10^{-6} For example, using Table 6-12, in the point estimate row, an RME rural resident who is exposed daily to 4 pCi/g of U-234 in soil over 30 years would have no greater than a 1 in 100,000 (10^{-5}) chance of developing cancer as a result of that exposure

For the probabilistic approach, the distribution of RSALs represents the variability in exposure within a population Similar to the dose-based calculations, the RME can be selected from the risk-based RSALs by focusing on the results corresponding to the RME range (i e , 90th to 99th percentiles of the dose distribution, or 10th to 1st percentiles of the RSAL distribution) The probabilistic estimate and the point estimate are presented side-by-side in Tables 6-12 and 6-18 for perspective The results are not expected to be identical The two methods represent different ways of arriving at a best estimate of the RME individual Significant differences in estimates of the RME can generally be explained by evaluating the inputs to the exposure equation Results of a sensitivity analysis can be used to highlight variables that are most likely to contribute to these differences When estimates are inconsistent (i e , the point estimate falls outside the 10th to 1st percentiles of the probabilistic RME range), the risk manager may still have confidence in the probabilistic RME range so long as the probability distributions for the key exposure pathways and variables are well characterized

Directly below each individual RSAL table is a table that lists the individual radionuclide RSALs as the sum-of-ratios RSALs that would apply when more than one isotope of uranium is present in the ratios normally found in depleted uranium or 20% enriched uranium (Table 6-13 and 6-19) These sum-of-ratio calculations were done only for the 5th percentile probabilistic RSALs and the point estimate RSALs at the 10^{-4} risk level A 10^{-4} risk level is presented in order to show values of uranium that may actually occur in soil, given high area background levels Site-specific data obtained from isotopic analysis could be used to calculate site-specific uranium sum-of-ratio RSALs that could be used as the basis for the actual cleanup, in lieu of the bounding sum-of-ratio RSALs presented here

Following the sum-of-ratios tables for each receptor are a series of tables that present the percent contribution by exposure pathway for both the probabilistic and point estimate calculations These percent contributions by exposure pathway are presented for both the depleted uranium and enriched uranium cases (Tables 6-14 through 6-17 for the rural resident, Tables 6-20 through 6-23 for the wildlife refuge worker) All of these exposure pathways were evaluated in the assessment, and the RSALs are protective for cumulative exposure across all these pathways All simulations are run with 10,000 iterations using Crystal Ball® (Decisioneering, Inc , 2001) As discussed for plutonium and americium, the results of the sensitivity analysis performed on the individual uranium isotopes determined which exposure variables dominated the risk-based RSAL calculations As with the plutonium and americium calculations, exposure duration had

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the greatest influence on the risk-based calculations, followed by plant transfer factors and plant food consumption rates, soil ingestion rates, and the mass loading

Unlike the assessment of plutonium and americium, the assessment of uranium also included calculations of RSALs using EPA's Standard Risk equations for non-carcinogens Uranium is different from plutonium and americium in that it exhibits significant chemical toxicity (i e , kidney toxicity) as well as radiological toxicity (i e , carcinogenic effects) To ensure that the final RSAL for uranium addresses both chemical and radiological toxicity, results are included in the individual radionuclide RSAL tables below (Tables 6-12 and 6-18)

Table 6-12 Risk-based uranium RSALs (probabilistic and point estimate) for individual radionuclides for the rural resident

Radionuclide	Percentile[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
U-238	10th	225	22	2 2
	5th	122	12	1 2
	1st	34	3	0 3
	Point estimate	40	4	0 4
U-235	10th	21	2	0 2
	5th	15	1	1 0
	1st	9	1	0 1
	Point estimate	11	1	0 1
U-234	10th	212	21	2 1
	5th	110	11	1 1
	1st	28	3	0 3
	Point estimate	36	4	0 4
Uranium (non-cancer)		**RSAL (µg/g) at Hazard Index of 1 0**		
	10th	738		
	5th	458		
	1st	199		
	Point estimate	669		

[1] 10th to 1st percentiles of RSAL distribution corresponds to 90th to 99th percentiles of risk distribution

Table 6-13 Risk-based RSALs for the rural resident from Table 6-12 adjusted by SOR method (probabilistic and point estimate)

Radionuclide	Statistic[1]	RSAL (pCi/g)		
		Individual	DU	EU
U-238	5th Percentile	122	77	3
	Point estimate	40	26	1
U-235	5th Percentile	15	1	5
	Point estimate	11	0 4	2
U-234	5th Percentile	110	32	72
	Point estimate	36	11	29

[1]Output is for the RSAL that corresponds to a 10^{-4} target risk
DU = depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

Table 6-14 Percent (%) contributions of exposure pathways to probabilistic risk-based RSALs for the rural resident using individual radionuclides and SOR method – depleted uranium (DU)

Exposure Pathway	U-238 (DU)		U-235 (DU)		U-234 (DU)		Total Uranium[2] (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 4	0 3	93 0	0 9	1 8	0 5	1 7
Inhalation	10 7	7 5	0 3	<0 1	11 3	3 3	10 8
Plant ingestion	59 9	41 9	5 5	<0 1	58 9	17 1	59 1
Soil ingestion	29 0	20 3	1 2	<0 1	28 0	8 1	28 4

[1]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29
[2] Sum of SOR adjusted % contribution from U-238, U-235, and U-234
SOR = sum-of-ratios

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Table 6-15. Percent (%) contributions of exposure pathways to point estimate risk-based RSALs for the rural resident using individual radionuclides and SOR method – depleted uranium (DU)

Exposure Pathway	U-238 (DU)		U-235 (DU)		U-234 (DU)		Total Uranium[2] (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 0	0 0	70 5	0 7	0 1	<0 1	0 7
Inhalation	3 4	2 4	1 0	<0 1	3 8	1 1	3 5
Plant ingestion	89 3	62 5	26 3	0 3	88 9	25 8	88 6
Soil ingestion	7 2	5 0	2 1	<0 1	7 2	2 1	7 2

[1]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29
[2] Sum of SOR adjusted % contribution from U-238, U-235, and U-234
SOR = sum-of-ratios

Table 6-16 Percent (%) contributions of exposure pathways to probabilistic risk-based RSALs for the rural resident using individual radionuclides and SOR method – enriched uranium (EU)

Exposure Pathway	U-238 (EU)		U-235 (EU)		U-234 (EU)		Total Uranium[2] (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 4	< 0 1	93 0	5 6	1 8	1 6	7 2
Inhalation	10 7	0 4	0 3	< 0 1	11 3	10 2	10 6
Plant ingestion	59 9	2 4	5 5	0 3	58 9	53 0	55 7
Soil ingestion	29 0	1 2	1 2	< 0 1	28 0	25 2	26 4

[1]The SOR RSALs for EU were calculated for an isotopic ratio of 4 6 90
[2] Sum of SOR adjusted % contribution from U-238, U-235, and U-234
SOR = sum-of-ratios

Table 6-17 Percent (%) contributions of exposure pathways to point estimate risk-based RSALs for the rural resident using individual radionuclides and SOR method – enriched uranium (EU)

Exposure Pathway	U-238 (EU)		U-235 (EU)		U-234 (EU)		Total Uranium[2] (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 0	0 0	70 5	4 2	0 1	< 0 1	4 3
Inhalation	3 4	0 1	1 0	< 0 1	3 8	3 4	3 6
Plant ingestion	89 3	3 6	26 3	1 6	88 9	80 0	85 2
Soil ingestion	7 2	0 3	2 1	0 1	7 2	6 5	6 9

[1]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90
[2] Sum of SOR adjusted % contribution from U-238, U-235, and U-234
SOR = sum-of-ratios

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Table 6-18 Risk-based uranium RSALs (probabilistic and point estimate) for individual radionuclides for the wildlife refuge worker

Radionuclide	Percentile[1]	RSALs (pCi/g) at Selected Target Risks		
		10^{-4}	10^{-5}	10^{-6}
U-238	10th	4,398	440	44.0
	5th	3,511	351	35.1
	1st	2,347	235	23.5
	Point estimate	2,095	210	21.0
U-235	10th	87	9	0.9
	5th	76	8	0.8
	1st	61	6	0.6
	Point estimate	69	7	0.7
U-234	10th	3,778	378	37.8
	5th	3,000	300	30.0
	1st	1,986	199	19.9
	Point estimate	1,781	178	17.8
Uranium (non-cancer)		RSAL (µg/g) at Hazard Index of 1.0		
	10th	2,920		
	5th	2,750		
	1st	2,576		
	Point estimate	3,066		

[1] 10th to 1st percentiles of RSAL distribution corresponds to 90th to 99th percentiles of risk distribution

Table 6-19 Risk-based RSALs for the wildlife refuge worker from Table 6-18 adjusted by SOR method (probabilistic and point estimate)

Radionuclide	Statistic[1]	RSAL (pCi/g)		
		Individual	DU	EU
U-238	5th Percentile	3,511	1,636	36
	Point estimate	2,095	1,092	29
U-235	5th Percentile	76	23	54
	Point estimate	69	16	43
U-234	5th Percentile	3,000	678	817
	Point estimate	1,781	452	647

[1] Output is for the RSAL that corresponds to a 10^{-4} target risk
DU= depleted uranium, EU = enriched uranium, SOR = sum-of-ratios

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Table 6-20. Percent (%) contributions of exposure pathways to probabilistic risk-based RSALs for the wildlife refuge worker using individual radionuclides and SOR method – depleted uranium (DU)

Exposure Pathway	U-238 (DU)		U-235 (DU)		U-234 (DU)		Total Uranium (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 8	0 5	98 2	1 0	3 1	0 9	2 4
Inhalation	42 9	30 0	0 8	<0 1	43 9	12 7	42 8
Plant ingestion	NA	NA	NA	NA	NA	NA	NA
Soil ingestion	56 3	39 4	1 0	<0 1	53 0	15 4	54 8

[1]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29
NA = not applicable, SOR = sum-of-ratios

Table 6-21 Percent (%) contributions of exposure pathways to point estimate risk-based RSALs for the wildlife refuge worker using individual radionuclides and SOR method

Exposure Pathway	U-238 (DU)		U-235 (DU)		U-234 (DU)		Total Uranium (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 3	0 2	96 5	1 0	1 2	0 4	1 5
Inhalation	54 1	37 9	1 9	<0 1	56 2	16 3	54 2
Plant ingestion	NA	NA	NA	NA	NA	NA	NA
Soil ingestion	45 6	32 0	1 6	<0 1	42 6	12 3	44 3

[1]The SOR RSALs for depleted uranium were calculated for an isotopic ratio of 70 1 29
SOR = sum-of-ratios

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Table 6-22 Percent (%) contributions of exposure pathways to probabilistic risk-based RSALs for the wildlife refuge worker using individual radionuclides and SOR method – enriched uranium (EU)

Exposure Pathway	U-238 (EU)		U-235 (EU)		U-234 (EU)		Total Uranium (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 8	< 0 1	98 2	5 9	3 1	2 8	8 7
Inhalation	42 9	1 7	0 8	< 0 1	43 9	39 5	41 2
Plant ingestion	NA	NA	NA	NA	NA	NA	NA
Soil ingestion	56 3	2 3	1 0	< 0 1	53 0	47 7	50 0

[1]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90
SOR = sum-of-ratios

Table 6-23 Percent (%) contributions of exposure pathways to point estimate risk-based RSALs for the wildlife refuge worker using individual radionuclides and SOR method – enriched uranium (EU)

Exposure Pathway	U-238 (EU)		U-235 (EU)		U-234 (EU)		Total Uranium (%)
	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	Individual Nuclide (%)	SOR[1] Adjusted (%)	
External	0 3	< 0 1	96 5	5 8	1 2	1 1	6 9
Inhalation	54 1	2 2	1 9	0 1	56 2	50 6	52 9
Plant ingestion	NA	NA	NA	NA	NA	NA	NA
Soil ingestion	45 6	1 8	1 6	0 1	42 6	38 3	40 2

[1]The SOR RSALs for enriched uranium were calculated for an isotopic ratio of 4 6 90
SOR = sum-of-ratios

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7.0 POINT ESTIMATE AND PROBABILISTIC APPROACHES TO CALCULATING RSALS FOR THE RME INDIVIDUAL

The EPA risk assessment guidance, (both *Risk Assessment Guidance for Superfund*, Section 6 1 2 of U S EPA, 1989 and the *NCP Preamble*, U S EPA, 1990) states that human health risk management decisions at Superfund sites should be based on an individual who has reasonable maximum exposure (RME) This is the individual who receives the highest exposures that would reasonably be expected to occur at this site The intent of the RME is to estimate a conservative (high-end) exposure case (i e , well above the average) that is still within the range of possible exposures based on both quantitative information and professional judgment (Sections 6 1 2 and 6 4 1 of U S EPA, 1989) Consistent with this guidance, one of the overall goals of site-specific RSAL calculations is to calculate soil concentrations that are protective of the RME receptor in the exposed population for each land use scenario

The traditional method for calculating RME has been to utilize a set of standard (default) point estimates for exposure variables that reflect the upper end of the distribution for the more sensitive variables in the risk or dose equations, coupled with average values for the less sensitive variables (U S EPA, 1991, 1992b) By using a combination of high-end and average values, risk assessors attempt to characterize conservative, yet plausible estimates of risk or dose This approach has been applied to support risk management decisions at sites for many years While still acceptable, one limitation of the point estimate approach is that it does not provide quantitative information about the degree of protectiveness of the RME For example, assume that information is available to determine the variability in exposure (and, therefore, risk) from multiple exposure pathways Using the point estimate approach, a risk assessor can determine a unique RSAL that corresponds to a target cancer risk of 10^{-4}, but it is unclear whether the RSAL is low enough that only 5% of the risk estimates exceed 10^{-4}, or a much higher percentage is expected

As discussed in Chapter 4, a point estimate approach was applied to each of the land-use scenarios to calculate both dose- and risk-based RSALs protective of the RME individual In cases where site-specific information was available, point estimates were selected to be representative of the RME individual In this assessment, the point estimate approach was the only method used to calculate RSALs for the Office Worker and Open Space User scenarios Results of the point estimate approach for dose and risk modeling are presented in Chapters 5 and 6

In addition, a probabilistic approach was applied to the Wildlife Refuge Worker and Rural Resident scenarios in order to quantify variability in exposure These two scenarios were selected for a probabilistic approach because they are considered most likely to actually occur at Rocky Flats Results for the Wildlife Refuge Worker scenario would apply to future land use with institutional controls, whereas the Rural Resident scenario is representative of future land use without institutional controls The working group decided that the greater information available from a probabilistic analysis would prove helpful in establishing and justifying RSALs for these more critical receptors Important steps in conducting a probabilistic risk assessment include identifying the input variables that are important contributors to the model output (risk or RSAL), and then developing probability distributions that characterize variability among the

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exposed population. Details regarding the sensitivity analysis approaches, Monte Carlo modeling methodology, and the derivation of point estimates and probability distributions used to characterize selected input variables are given in Chapter 4 and Appendix A. The results of the probabilistic approach for both the dose and risk modeling are given in Chapter 5 and Chapter 6.

By quantifying the contribution of variability in the key variables to the dose, risk or RSAL estimates, and defining the level of confidence in the estimate to a greater extent, a more precise estimate of RME at any given target risk or dose level can be attained with a probabilistic approach. Since the probabilistic approach yields a probability distribution for RSALs, a range of percentiles from the output distribution is presented for each scenario for americium, plutonium, and uranium. Each distribution of RSALs only reflects variability in exposure. EPA defines the 90th to 99th percentiles of a *risk* distribution as the recommended RME range, with the 95th percentile as the starting point for risk-decision making (U.S. EPA, 2001b). Because RSAL calculations are essentially the inverse of risk calculations, the RME range for the RSAL distribution corresponds to the 10th to 1st percentiles, with the 5th percentile as the recommended starting point for risk decision-making. Decision makers are encouraged to select higher percentiles (to be less conservative) or lower percentiles (to be more conservative) within the RME range, depending on site-specific information on the variability and uncertainty in the risk assessment. This chapter summarizes the information on variability and uncertainty most relevant to each scenario, focusing on how this information may guide the selection of a percentile from the RSAL output distribution that can be considered representative of the RME individual.

7.1 VARIABILITY AND UNCERTAINTY IN PROBABILISTIC RISK ASSESSMENT

Prior to developing probability distributions for use in a risk assessment, it is important to clearly understand the distinction between variability and uncertainty. Both variability and uncertainty affect the choice of the RSAL that corresponds with the RME individual. Variability refers to true heterogeneity or diversity that occurs within a population or sample. For example, among an exposed population of individuals who incidentally ingest soil from the same source and with the same contaminant concentration, the risks from that ingestion may vary. This may be due to differences in exposure (e.g., different people ingesting different amounts of soil, having different body weights, different exposure frequencies, and different exposure durations), as well as differences in response (e.g., genetic differences in resistance to a chemical dose, or physiological differences in amount of soil absorbed from the gastrointestinal tract). Uncertainty occurs because of a lack of knowledge about parameters, models, or scenarios. It is not the same as variability, although there is typically uncertainty in probability distributions and parameter estimates that are selected to characterize variability.

Collecting a higher quantity and quality of data can often reduce uncertainty, while variability is an inherent property of the particular population or dataset. Variability can be better characterized with more data, but it cannot be reduced or eliminated (U.S. EPA, 2001b). While variability can affect the precision of risk (or RSAL) calculations, uncertainty can lead to inaccurate or biased estimates. For example, a survey of food ingestion rates among the U.S. population may yield a large sample size that is well characterized by an empirical distribution

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for variability, however, unless certain factors are taken into consideration (e g , homegrown fraction, geographic location, seasonality), the distribution may not represent a future rural resident population at Rocky Flats In order to reduce uncertainty, the characteristics of the surveyed population are also needed in order to identify the subset of the data that best characterizes the exposed population See Appendix A for a complete discussion of the factors that were considered in order to reduce uncertainty in the probability distributions developed for food ingestion rates and other variables in the probabilistic risk assessment

In probabilistic risk assessment, variability can be quantified by the probability distributions used to characterize input variables as well as by the modeling approach used to quantify long-term average exposures *Inter-individual variability* refers to differences among individuals in a population, whereas *intra-individual variability* refers to differences for one individual over time (U S EPA, 2001a) In this assessment report, probability distributions were developed to explicitly characterize inter-individual variability Intra-individual variability is addressed in the development of parameter estimates from available data A relatively straightforward Monte Carlo modeling approach was used whereby each random value selected from a probability distribution is intended to characterize a long-term average characteristic of a hypothetical individual For example, inter-individual variability in soil ingestion rate for children is characterized by a truncated lognormal distribution (Log (47 5, 112, 0, 1,000) mg/day), as discussed in Appendix A (A 1 2) and summarized in Table 4-5 A random value from this distribution (e g , 75 mg/day) would be considered representative of a hypothetical individual's average soil ingestion rate during ages 0 to 6 years The impact on the RSALs from each source of variability is summarized in Section 7 3

For some Monte Carlo models, it may be helpful to also characterize uncertainty with a probability distribution For example, uncertainty in the arithmetic mean of a sample can be described by a probability distribution of means If probability distributions for variability and probability distributions for uncertainty are developed for use in probabilistic risk assessment, it is important to incorporate a simulation strategy that distinguishes between the two types of distributions When used appropriately, this approach can yield confidence limits on the percentiles of the output distribution (e g , RSALs) When distributions are combined inappropriately, it is unclear whether an output distribution reflects variability or uncertainty

As discussed above, for the RSAL calculations in this assessment, probability distributions were selected to characterize inter-individual variability in long-term average exposures (e g , years) Since most of the published information that is relevant to exposure assessment is collected over short time periods (e g , days or weeks), estimates of long-term average exposure must be either inferred or calculated from short-term measurements This extrapolation represents a source of uncertainty in the development of both point estimates, and probability distributions that characterize variability

An overview and qualitative discussion of the major sources of uncertainty in the derivation of RSALs is presented in this chapter A more comprehensive overview of the uncertainties associated with the selected probability distributions is given in Appendix A No attempt was made to conduct a quantitative uncertainty analysis by simultaneously characterizing variability and uncertainty in the Monte Carlo simulations (sometimes referred to as two-dimensional

Monte Carlo analysis Nevertheless, a qualitative discussion of the sources of uncertainty in key exposure pathways and exposure variables is presented In addition, a qualitative confidence rating is given for each of the variables characterized by a probability distribution

Uncertainty can be classified into three broad categories, as applied to risk assessment, according to EPA's *Final Guidelines for Exposure Assessment* (U S EPA, 1992a) and the *Exposure Factors Handbook* (U S EPA, 1997)

(1) **Parameter Uncertainty** – lack of knowledge about values assigned to estimate parameters for input variables in a risk assessment model Parameter uncertainty can be introduced in each step of the risk assessment process, from data collection and evaluation, to the assessment of exposure and toxicity Sources of parameter uncertainty can include systematic errors or biases in the data collection process, imprecision in the analytical measurements, inferences made from a limited database, and extrapolation or the use of surrogate measures to represent the parameter of interest (U S EPA, 2001b) The point estimate selected to characterize the exposure duration (i e , number of years in an occupation) for the RME individual in the Office Worker scenario is an example of parameter uncertainty A variety of occupations may be available in a future office park, each of which may be characterized by different job tenures The standard default RME point estimate of 25 years (U S EPA, 1991) was selected for occupational exposure duration, the working group felt this is a reasonable maximum duration that most office workers are likely to work in one location

(2) **Model Uncertainty** – lack of knowledge about model structure or use, whether the mathematical models or equations used to define exposure variables (e g , mass loading factor, soil-to-plant transfer factor) and calculate risk, dose, or RSAL, adequately describe the physical or biological processes of interest All models are simplified, mathematical representations of complicated physical or biological conditions They may not always adequately represent all aspects of the phenomena they are intended to approximate or may not always capture important relationships among input variables (U S EPA, 2001b) Sources of model uncertainty can be introduced when important variables are excluded, interactions between inputs are ignored or simplified, or surrogate data are used to characterize exposures to the target population

An example of model uncertainty is the selection of a model for dose conversion factors (dose conversion factors) that accurately describes how particulates are handled by the lung The ICRP 72 (ICRP, 1996) dose conversion factors were selected over the ICRP 30 values (ICRP, 1979) It was decided that the newer lung model used in the ICRP 72 calculations more accurately described how various parts of the respiratory system are impacted by particulates and in turn how absorption takes place in the various regions

(3) **Scenario Uncertainty** – lack of knowledge necessary to fully define exposure, particularly to potential receptors in the future The choice of which receptors (e g , adult or child, open space user, etc) represent the target population in an assessment necessarily requires professional judgment A variety of factors may influence the

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selection, including local population growth characteristics and current conditions, such as political, social and economic concerns In addition, characteristics of a particular future land use scenario are often uncertain Table 3-2 provides a profile of assumptions for each scenario The working group included any exposure pathways that are reasonably likely to contribute to risks to the potentially exposed population of concern The working group also used available site-specific information, such as the amount of water available in the perched, shallow hydrostratigraphic unit, in order to minimize uncertainties in the exposure assessment The target population for the Wildlife Refuge Worker scenario is defined as an on-site population that may be exposed within the next 50 to 100 years when institutional controls are still in place By contrast, the Rural Resident scenario represents a potential onsite condition in the future when institutional controls no longer exist There is scenario uncertainty intrinsic in all of these choices

The cumulative impact of uncertainties in the risk assessment can provide compelling reasons for moving away from the starting point (i e , 5th percentile) of the RSAL distribution to define the RME This chapter discusses uncertainties associated with the models, exposure scenarios, and parameters used in the dose- and risk-based RSAL calculations The cumulative effect of these uncertainties is summarized at the end of the chapter, and a recommendation is made for either staying with the midpoint or moving to a higher or lower value within the health-protective RME range (See Section 7 6)

7.2 USE OF SENSITIVITY ANALYSIS TO SELECT VARIABLES FOR PROBABILISTIC ANALYSIS

As discussed in Chapter 4 (see Figure 4-1 and accompanying text), the probabilistic risk assessment presented here uses probability distributions to characterize variability in dose and risk estimates Only those variables identified from the point estimate sensitivity analysis as being high or moderate contributors to the model output are described by probability distributions As shown in Table 4-4, the most sensitive variables identified by the sensitivity analysis are indoor time fraction and the soil ingestion rate Moderately sensitive input variables for which data are available in sufficient quantity and quality to allow derivation of distributions are fruit, vegetable, and grain consumption rates, inhalation rate, and the soil-to-plant transfer factor for uranium Even though the mass loading variable was not very sensitive overall, RESRAD's sensitivity analysis showed it to be sensitive for the inhalation pathway Therefore, a probability distribution was derived for mass loading In addition, for the risk-based approach, exposure duration was also selected for probabilistic analysis The remaining input variables are described by point estimates Therefore, the characterization of variability in this assessment focuses on the most important variables, as indicated by the sensitivity analysis The complete set of point estimates and probability distributions used in this analysis are given in Chapter 4 (for risk calculations) and Appendix D (for dose calculations)

Probabilistic sensitivity analysis, such as was done to determine the most important variables contributing to the risk estimates, may yield different results than the point estimate sensitivity-ratio approach, such as that used by RESRAD This is because the probability sensitivity analysis demonstrates the combined effect of variability in inputs rather than the effect of changes in only one input variable at a time Appendix H gives the complete set of probabilistic

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sensitivity analysis results in tornado plots for risk calculations done on the Rural Resident and Wildlife Refuge Worker scenarios An analysis was not applied to the dose-based RSAL calculations using RESRAD, since the RESRAD user interface is designed to allow a sensitivity analysis by varying only one variable at a time A guide to the tables and figures that summarize the risk-based and dose-based RSALs in this assessment report is given in Tables 7-1 and 7-3 for the rural resident and wildlife refuge worker, respectively

It should be noted that EPA policy recommends against developing site-specific probability distributions for human health toxicity values at this time, so point estimates recommended by the ICRP or EPA were used for dose conversion factors and cancer slope factors, respectively, in the probabilistic analysis (U S EPA, 2001a)

7.3 IMPACT OF VARIABILITY ON THE RSAL

A variety of distributions were used to characterize variability in exposure (see Tables 4-5 and 4-6, and Appendices A and D) The distribution type selected for a particular input variable reflects the empirical data available from the literature and the working group's professional judgment The combined impact of the variability in all of the individual input distributions is demonstrated by the output RSAL distribution The 1st, 5th, and 10th percentiles of the risk-based plutonium and americium RSAL distributions calculated at the 10^{-4}, 10^{-5}, and 10^{-6} risk levels are shown in Tables 5-1 and 5-2 for the Rural Resident scenario and Tables 5-5 and 5-6 for the Wildlife Refuge Worker scenario The 5th percentile RSALs from probabilistic dose-based calculations at the 25-mrem level for these two receptor populations and radionuclides are presented in Tables 5-16, 5-17, and 5-19 The uranium RSAL distributions are presented in Tables 6-12, 6-13, 6-18, and 6-19 for the risk-based calculations, and Tables 6-7 through 6-9 for the dose-based calculations

Compared to a simple point estimate calculation of an RSAL, such as was done in the 1996 RSAL calculations and which is also presented in this report, a probabilistic approach can more completely and accurately characterize variability in risk when information is available for the more influential exposure variables By definition, the point estimate approach reduces the variability to a series of point estimates corresponding to central tendency and reasonable maximum exposure (CTE and RME) Results of the point estimate approach cannot be directly related to the full distribution of exposures, and should, therefore, not be compared to the results of the probabilistic approach For example, in calculations of cancer risk, the RME determined from the point estimate approach could be the 90th percentile, the 99th percentile, or some other point on the distribution Without knowing what percentile is represented by the RME, it is more difficult to determine and communicate the likelihood that the RSAL (soil concentration) will be protective of the exposed population It also becomes more difficult to decide what level of remedial action is justified or necessary in order to achieve the objectives of the NCP (see Table 5-15)

As stated in Chapter 5, a probabilistic approach provides a distribution of risk or RSAL values from which an RME may be selected The RME range (i e , the range of values that may be protective of the RME receptor) corresponds to the 10th to 1st percentiles of the RSAL distribution, and the 90th to 99th percentiles for the risk distribution While the Monte Carlo

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analysis is an effective approach to combine multiple sources of variability simultaneously, the choice of the percentile that corresponds to the RME is a risk management decision Following EPA guidance on performing probabilistic risk assessment (U S EPA, 2001b), a starting point for selecting the RSAL is the 5th percentile of the RSAL distribution Information on variability and uncertainty is presented in this chapter to guide the final selection of a percentile value that is representative of the RME individual

The sensitivity analysis applied to the RSAL calculations for individual radionuclides yields information on the relative contributions of exposure pathways and exposure variables For this assessment, the risk-based results of the sensitivity analysis are independent of the target risk level In general, an exposure pathway may dominate risk or RSAL estimates if it contributes the greatest fraction of the total dose, and/or it is associated with the greatest cancer slope factor Likewise, an exposure variable is likely to have greater influence on the variability in RSAL if it has one or more of the following three characteristics

(1) It is a factor in a major exposure pathway,
(2) It is a factor in multiple exposure pathways, and
(3) It has a relatively high coefficient of variation (i e , ratio of standard deviation to the mean) compared with other exposure variables in the same exposure pathway

The collective impact of all of the sources of variability in exposure is represented by the distribution of RSALs In general, the greater the number of input variables that are characterized by probability distributions, the greater the variance in the output distribution Since risk managers will tend to focus on the lower tail of the RSAL distribution (10th to 1st percentiles) to select an RME value, the variability in the RSALs within the range may determine whether or not further effort is needed to evaluate sources of variability and uncertainty If the results vary significantly (e g , multiple orders of magnitude) between the 10th and 1st percentiles, the choice of the percentile that characterizes the RME individual is more important than if the RSAL values only range by a factor of two In addition, when comparing the point estimate of the RME to the probabilistic results, the point estimate RME value may be more likely to fall outside the probabilistic RME range as the variance in the output distribution decreases

7.3.1 Wildlife Refuge Worker Scenario

Table 4-6 summarizes the distributions used for exposure variables for the Wildlife Refuge Worker scenario Table 7-1 provides cross-references to the results of the probabilistic analysis using the Standard Risk equations, which are presented in Chapter 5 and Appendix H

7.3.1 1 RME Range

The results of the probabilistic risk assessment using Standard Risk equations for the wildlife refuge worker suggest that the RME range is relatively narrow for both americium and plutonium For example, at a target risk level of 10^{-4}, the 10th to 1st percentile range for americium is 904 to 560 pCi/g (i e , a factor of approximately 1 6), with a 5th percentile RSAL (RME starting point) of 760 pCi/g (see Table 5-5) By comparison, the point estimate RME of 514 pCi/g at this target risk level falls outside the RME range, and would yield a more

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conservative RSAL value Similarly, the 10^{th} to 1^{st} percentile range for plutonium at a target risk level of 10^{-4} is 1,472 to 737 pCi/g (a factor of two), with a 5^{th} percentile RSAL of 1,160 pCi/g The point estimate RME for plutonium of 670 pCi/g also falls just below the probabilistic RME range for plutonium

The results of the probabilistic risk assessment using the dose-based approach suggest that the RME ranges for SOR-adjusted RSALs are also narrow Estimating the 99^{th} percentiles of the annual doses from the 50^{th}, 90^{th}, and 95^{th} percentiles applied to a lognormal distribution, the RME ranges for americium and plutonium vary by less than a factor of 1 5

For uranium radionuclides and chemical toxicity (non-cancer), the RME range for the risk-based RSALs vary by less than a factor of two The following is the relative rank order of the spread in the RME range (Table 6-18) U-234 > U-238 > U-235 > U –non-cancer By contrast, the relative rank order of 5^{th} percentile RSALs (Table 6-19) is as follows for SOR-adjusted depleted uranium U-235 < U-234 < U-238 For enriched uranium, the relative rank order of 5^{th} percentile RSALs is as follows U-238 < U-235 < U-234

Table 7-1 Guide to results of RSAL calculations and sensitivity analysis for Wildlife Refuge Worker scenario

Results		**Standard Risk Equations**	**Dose Calculations RESRAD 6 0**
Americium	Point estimates, probabilistic estimates of RSALs[1]	Table 5-5	Table 5-19
	Sum-of-ratios adjusted RSAL[2]	Table 5-6	Table 5-19
	Sensitivity analysis – percent contribution of exposure pathways	Table 5-7 (prob) Table 5-8 (point est)	Table 5-20
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available
Plutonium	Point estimates, probabilistic estimates of RSALs[1]	Table 5-5	Table 5-19
	Sum-of-ratios adjusted RSAL[2]	Table 5-6	Table 5-19
	Sensitivity analysis – percent contribution of exposure pathways	Table 5-7 (prob) Table 5-8 (point est)	Table 5-20
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available
Uranium	Point estimates, probabilistic estimates of RSALs[1]	Table 6-18 (includes non-cancer RSAL)	Table 6-9 (pCi/g) Table 6-10 (µg/g) Table 6-11 (scaled to body weight)
	Sum-of-ratios adjusted RSAL[2]	Table 6-19	Table 6-9, Table 6-10, and Table 6-11

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Results		Standard Risk Equations	Dose Calculations RESRAD 6 0
	Sensitivity analysis – percent contribution of exposure pathways	Table 6-20 (prob , depleted uranium) Table 6-21 (point est , depleted uranium) Table 6-22 (prob , enriched uranium) Table 6-23 (point est , enriched uranium)	Not available
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available

[1]Probabilistic result is the RME Range (1st, 5th, 10th percentiles) for Standard Risk equations, and 5th percentile for the RESRAD dose-based approach

[2]Accounts for additional activity from Am-241 using a sum-of-ratios method, and assumes that the Am Pu activity ratio equals 0 182 and that only Am and Pu are present For uranium, assumes that U-238, U-235 and U-234 are present in ratios consistent with either depleted uranium (70 1 29) or as 20% enriched uranium (4 6 90)

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7 3.1.2 RELATIVE CONTRIBUTIONS OF EXPOSURE PATHWAYS

For the wildlife refuge worker, the external exposure pathway dominates the probabilistic risk-based RSAL calculation for americium by contributing approximately 58% to the risk, followed by inhalation (22%) This result suggests that exposure variables that are unique to the external exposure pathway can be expected to also contribute more to the variance in the americium RSAL distribution Appendix B gives the Standard Risk equations and Chapter 4 gives the summary of point estimates and probability distributions used in the RSAL calculations For the external exposure pathway, the only variables that are described with probability distributions are exposure duration and exposure frequency Probabilistic risk-based RSAL calculations for plutonium are dominated approximately equally by soil ingestion (50%) and inhalation (49%) For the inhalation pathway, the probabilistic variables include the same set of time averaging variables as external radiation, plus inhalation rate and mass loading For soil ingestion, the probabilistic variables include exposure duration, exposure frequency, and soil ingestion rate

For the SOR adjusted values for Am and Pu, which weight plutonium results more heavily than americium, the probabilistic approach yields the following ranking of pathways soil ingestion (46%) > inhalation (45%) > external exposure (10%) For the point estimate approach, soil ingestion dominates with 55% of contribution to risk-based RSAL, followed by inhalation (42%) and external exposure (4%)

For the dose-based RSALs, the relative contribution of three exposure pathways, based on SOR-adjusted estimates for Am and Pu, are as follows soil ingestion (80%) > inhalation (16 1%) > external exposure (3 7%) These results are consistent with the risk-based SOR approach

For uranium, the percent contributions of exposure pathways are presented separately for depleted uranium (Tables 6-20 and 6-21) and enriched uranium (Tables 6-22 and 6-23) In terms of the relative ranking of the three exposure pathways, the probabilistic results are somewhat different between the point estimate results for both depleted uranium and enriched uranium For depleted uranium, soil ingestion (56%) is the major contributor to the probabilistic risk based RSAL for total uranium, followed by inhalation (43%) For the corresponding point estimate analysis, inhalation is the major pathway (54%), followed by soil ingestion (44%) This suggests that one or more variables in the soil ingestion pathway have a relatively high coefficient of variation, and that the point estimate value does not lie in the high end of the distribution Table7-2 provides a comparison of the point estimates and probability distribution for the exposure variables in the soil ingestion pathway that are characterized by probability distributions The point estimates for inhalation rate and soil ingestion rate correspond to a low-end and moderately high percentile, confirming the assessment of exposure pathway contributions

External exposure is a relatively minor pathway in all cases for uranium, with a maximum contribution of 9% for the probabilistic risk-based RSAL for enriched uranium (Table 6-22)

Table 7-2 Comparison of point estimates and probability distributions for exposure variables associated with the soil ingestion rate exposure pathway of the Wildlife Refuge Worker scenario

Exposure Variable	Probability Density Function (PDF)[1]	Point Estimate	
		Value	Percentile of PDF
Inhalation rate (m^3/hr)	Beta (1 79, 3 06, 1 1, 2)	1 3	27th %ile
Exposure frequency (days/yr)	Truncated normal (225, 10 23, 200, 250)	250	100th %ile
Exposure duration (years)	Truncated normal (7 18, 7 00, 0, 40)	18 7	95th %ile
Soil ingestion rate (mg/day)	Uniform (0, 130)	100	77th %ile
Mass loading ($\mu g/m^3$)	Empirical distribution function (see Table 4-5)	67	95th %ile

[1]The same probability density function was used in the RESRAD 6 0 probabilistic simulations, converted to units for calculating annual dose Exposure duration is described as a one-year point estimate in RESRAD

7.3.1.3 RELATIVE CONTRIBUTIONS OF EXPOSURE VARIABLES

In probabilistic risk assessment, the probability distributions defined for input variables can be related to the variability in potential RSALs by using a variety of sensitivity analysis approaches As discussed in Section 7 3, the exposure variables that are likely to contribute most to variability in risk assessment are those that are a factor in a major exposure pathway, a factor in multiple exposure pathways, and are defined by a probability distribution with a high coefficient of variation Results are presented as tornado plots in Appendix H Contribution to variance is calculated as the squared Spearman Rank correlation coefficients, normalized to sum to 100% Probabilistic sensitivity analysis approaches were not applied to the dose-based calculations of RSALs Instead, RESRAD applies sensitivity analysis to the point estimate calculations, based on sensitivity ratios (see Section 4 3)

Since exposure duration satisfies each of the three criteria listed in Section 7 3 for high contributions to variance, it can be expected that this variable will dominate the variance in the risk-based RSAL Appendix H, Tables H-5 and H-6 give tornado plots for americium and plutonium for the wildlife refuge worker For americium, exposure duration accounts for approximately 93% of the variance in RSAL, whereas for plutonium, it accounts for approximately 71% For americium, no other exposure variables contribute significantly to variance For plutonium, soil ingestion and mass loading are also relatively important, contributing 15% and 13%, respectively (Figure H-6)

For uranium, the sensitivity analysis results are presented for individual radionuclides as tornado plots in Appendix H, Tables H-15 to H-17 Exposure duration contributes approximately 70% to variance for U-234 and U-238, and approximately 99% for U-235 The soil ingestion rate contributes 18% for U-234 and 20% for U-238 In addition, the mass loading factor contributes 10% for both U-234 and U-238 The remaining two exposure variables that are described by probability distributions are exposure frequency and inhalation rate, both of which are minor contributors (i e , < 1%) for all three uranium radionuclides For the uranium non-cancer risk

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assessment, the probabilistic calculations yield a very different result since exposure duration is not a contributing factor to variance (i e , it cancels out of the risk equation) Soil ingestion rate contributes nearly all of the variance (i e , 99 5%)

7.3.1.4 OVERALL IMPACT OF VARIABILITY ON RME VALUE

For americium and plutonium together, the soil ingestion and inhalation exposure pathways together contribute nearly 90% to the total risk-based RSAL for the SOR analysis Similarly, for the dose-based approach, these pathways contribute 96% to the total dose Thus, the variability associated with exposure variables in these pathways is most relevant The key variables are exposure duration, soil ingestion rate, and inhalation rate

For uranium, soil ingestion and inhalation pathways contribute approximately equally to the risk-based RSAL The exposure variables for both pathways may be evaluated more closely to select the appropriate percentile of the RSAL distribution to characterize the RME Information about the RME range can assist in determining an appropriate percentile value from the RSAL distribution to represent the RME If the variability in an RSAL distribution is high, the RME range (i e , 1st to 10th percentiles) may span an order of magnitude or more In such cases, the difference between the 5th percentile and 6th percentile, for example, may result in very different RSAL values By contrast, a relatively narrow RME range relaxes the need to rigorously explore the contributions to variability and uncertainty in the model For this probabilistic risk assessment, given the relatively narrow RME ranges for all radionuclides, the 5th percentile is a reasonable choice for characterizing the RME Uncertainty in the dominant exposure pathways and variables are discussed further in Section 7 4

7.3.2 Rural Resident Scenario

Table 4-5 summarizes the distributions used for exposure variables for the Rural Resident scenario Table 7-3 provides cross-references to the results of the probabilistic analysis using the Standard Risk equations and RESRAD simulations The results are summarized in Chapters 5 and 6, and details are provided in the Appendices

Table 7-3 Guide to results of RSAL calculations and sensitivity analysis for Rural Resident scenario

Results		Standard Risk Equations	Dose Calculations RESRAD 6 0
Americium	Point estimates, probabilistic estimates of RSALs[1]	Table 5-1	Table 5-16 (adult) Table 5-17 (child)
	Sum-of-ratios adjusted RSAL[2]	Table 5-2	Table 5-16 (adult) Table 5-17 (child)
	Sensitivity analysis – percent contribution of exposure pathways	Table 5-3 (prob) Table 5-4 (point est)	Table 5-18 (SOR adjusted)
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available
Plutonium	Point estimates, probabilistic estimates of RSALs[1]	Table 5-1	Table 5-16 (adult) Table 5-17 (child)
	Sum-of-ratios adjusted RSAL[2]	Table 5-2	Table 5-16 (adult) Table 5-17 (child)
	Sensitivity analysis – percent contribution of exposure pathways	Table 5-3 (prob) Table 5-4 (point est)	Table 5-18 (SOR adjusted)
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available
Uranium	Point estimates, probabilistic estimates of RSALs[1]	Table 6-12 (includes non-cancer RSAL)	Table 6-7 (adult) Table 6-8 (child) Table 6-10 (µg/g) Table 6-11 (scaled to body weight, µg/g)
	Sum-of-ratios adjusted RSAL[2]	Table 6-13	
	Sensitivity analysis – percent contribution of exposure pathways	Table 6-14 (prob , depleted uranium) Table 6-15 (point est , depleted uranium) Table 6-16 (prob , enriched uranium) Table 6-17 (point est , enriched uranium)	Table 6-2

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Results		Standard Risk Equations	Dose Calculations RESRAD 6 0
	Sensitivity analysis – correlations and relative contributions to variance of exposure variables	Appendix H	Not available

[1]Probabilistic result is the RME Range (1st, 5th, 10th percentiles) for Standard Risk Equations, and 5th percentile for the RESRAD dose-based approach Results of RESRAD (Appendix E) are available on CD-ROM
[2]Assumes that the Am Pu activity ratio equals 0 182 and that only Am and Pu are present For uranium, assumes that U-238, U-235, and U-234 are present in ratios consistent with either depleted uranium (70 1 29) or as 20% enriched uranium (4 6 90)

7.3.2 1 RME RANGE

Risk-based RSALs

The RME range, given by the 10th to 1st percentiles, provides two types of information for decision making—an estimate of the RSAL at different percentiles of the distribution, and a measure of variability given by the "spread" of the values within the range The results of the probabilistic risk assessment using Standard Risk equations suggest that the RME range is relatively narrow for both americium and plutonium For example, at a target risk level of 10^{-4}, the 10th to 1st percentile range for americium is 145 to 39 pCi/g (i e , a factor of approximately four), with a 5th percentile RSAL (RME starting point) of 93 pCi/g (see Table 5-1) The point estimate RME is 70 pCi/g at this target risk level Similarly, the 10th to 1st percentile range for plutonium at a target risk of 10^{-4} is 439 to 139 pCi/g (a factor of three), with a 5th percentile RSAL of 284 pCi/g The analogous point estimate RME for plutonium of 128 pCi/g falls outside the probabilistic RME range, and would yield a more conservative (i e , lower) RSAL value Given the RME ranges are narrow for the individual radionuclides, similar results are found for the sum-of-ratio (SOR) adjusted values (see Table 5-2)

For uranium, the probabilistic RME range can be evaluated for each individual radionuclide The SOR calculations were done only for the 5th percentile of the RSAL distribution The widest RME range is estimated for U-234 (factor of 7 5) followed by U-238 (factor of 6 6) and U-235 (factor of 2 3) While the assessment for U-234 yields the widest range of RSALs, it does not yield the lowest RSALs, or highest RME risk The highest risk, as determined by the 5th percentiles of the individual radionuclide calculations, is given by U-235 (15 pCi/g), followed by U-234 (110 pCi/g), and U-238 (122 pCi/g) The narrow RME range for U-235 gives less importance to the choice of percentile that corresponds to the RME The point estimate for each isotope falls in the lower portion of the RME range, between the 1st and 5th percentiles For chemical toxicity (non-cancer), the 10th to 1st percentile range at a target hazard index of 1 0 is 738 to 199 µg/g, or a factor of 3 7

The most relevant metric of risk for uranium is given by the SOR adjusted RSALs, which can be evaluated for both depleted uranium and enriched uranium For depleted uranium, the 5th percentiles yield RSALs in the following rank order U-235 < U-234 < U-238 However, for enriched uranium, the 5th percentiles yield RSALs in the following ranking U-238 < U-235 < U-234

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Dose-based RSALs Using RESRAD

The results of the probabilistic assessment using dose-based equations suggest that the RME range is relatively narrow for both americium and plutonium Note that the RME range for dose-based results reflects the upper tail of the dose distribution, rather than the lower tail of the RSAL distribution In this case, higher percentiles correspond with lower RSAL values, so the RME range is given by the 90th to 99th percentiles RESRAD provides an estimate of the low end (90th percentile) and midpoint (95th percentile), but not the high-end (99th percentile) of the RME range The 99th percentile can be estimated by fitting the reported percentiles to a distribution and extrapolating the estimate of the 99th percentile For example, the probabilistic dose-based RSALs for plutonium for the adult rural resident (Table 5-16) yields a 50th, 90th, and 95th percentile RSAL at annual doses of 2 14, 3 65, and 4 48 mrem/yr per 100 pCi/g, respectively These percentiles can describe a lognormal distribution (geometric mean of 2 14 mrem/yr per 100 pCi/g, geometric standard deviation of 1 59), which yields a 99th percentile of 6 13 mrem/yr per 100 pCi/g The RME range varies by a factor of approximately 1 7 for this example A similar approach for americium yields an RME range that varies by a factor of approximately 3 3 As with the risk-based approach, the relatively narrow RME ranges from the dose-based approach for americium and plutonium yield SOR adjusted RSALs that also have narrow ranges A narrow RME range gives less importance to the choice of percentile that corresponds to the RME

For uranium, the selected percentiles of the probability distributions for SOR adjusted RSALs reported in Table 6-7 were used to define lognormal distributions, and thereby estimate the high-end of the RME range (i e , 99th percentile doses) The RME range is most variable for U-234 (factor of 4 7), followed by U-238 (factor 1 86), and U-235 (factor 1 22) The 5th percentile estimates of RSALs for depleted uranium and enriched uranium follow the same patterns as in the risk-based estimates described above For depleted uranium, the 5th percentiles yield RSALs in the following rank order U-235 < U-234 < U-238 However, for enriched uranium, the 5th percentiles yield RSALs in the following ranking U-238 < U-235 < U-234

7.3.2.2 RELATIVE CONTRIBUTIONS OF EXPOSURE PATHWAYS

The percent contributions of exposure pathways differ for individual radionuclides In addition, using a probabilistic approach, the percent contribution changes with each iteration of a Monte Carlo model, resulting in a probability distribution for percent contribution for each exposure pathway The arithmetic mean of the percent contribution probability distribution is presented in this analysis

The external exposure pathway dominates the probabilistic risk-based RSAL calculation for americium (Table 5-3) by contributing approximately 50% to the risk, followed by food ingestion (29%) This result suggests that exposure variables that are unique to the external exposure pathway can be expected to also contribute more to the variance in the RSAL distribution Appendix B gives the Standard Risk equations and Chapter 4 gives the summary of point estimates and probability distributions used in the RSAL calculations For the external exposure pathway, the only variables that are described with probability distributions in the risk calculation are exposure duration, exposure frequency, and exposure time Risk-based RSAL

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calculations for plutonium are dominated by soil ingestion (50%) and inhalation (32%) For the inhalation pathway, the probabilistic variables include the same set of time averaging variables as external radiation, plus inhalation rate and mass loading For soil ingestion, the probabilistic variables include exposure duration, exposure frequency, and soil ingestion rate When the results for americium and plutonium are combined by the SOR approach, soil ingestion (45%) and inhalation (29%) continue to be the dominant exposure pathways

For uranium, the percent contributions of exposure pathways are presented separately for depleted uranium (Tables 6-14 and 6-15) and enriched uranium (Tables 6-16 and 6-17) In terms of the relative ranking of the four exposure pathways, the probabilistic results are similar to the point estimate results for both depleted uranium and enriched uranium In all cases, the following is the rank order of percent contribution to RSALs plant ingestion > soil ingestion > inhalation > external exposures The plant ingestion pathway contributes between 60% and 80% of the total exposure Although external exposure is the dominant exposure pathway for U-235 for the individual radionuclide analysis, U-235 received little weight in the isotopic ratios used to calculate total uranium for depleted uranium and enriched uranium (see Tables 6-14 and 6-15) The maximum contribution of the inhalation pathway is 11%

For the probabilistic dose-based calculations of RSALs for americium, plutonium, and uranium, percent contributions of exposure pathways are based on the 5th percentiles of the RSAL distribution For americium and plutonium (SOR adjusted, Table 5-18), the following is the rank order of percent contribution to RSALs soil ingestion > plant ingestion > inhalation > external exposure For the child rural resident, soil ingestion comprises approximately 69% of the total dose-based RSAL, followed by plant ingestion (18%) For the adult rural resident, the contributions of soil ingestion and plant ingestion are approximately equal (45% and 40%, respectively) For both age groups, external exposure comprises less than 5% of the total exposures

For the dose-based calculations of RSALs for uranium, the sensitivity analysis suggests that the percent contribution of exposure pathways depends on the size of the exposure area (Table 6-2) For small areas (e g , 100 m^2), the external exposure pathway dominates the RSAL calculations for both depleted uranium and enriched uranium However, for large areas (40,000 m^2), the plant ingestion pathway dominates the exposures The protectiveness of the modeling assumptions employed in the Rural Resident scenario is discussed in Sections 6 4 and 6 5 A relatively large exposure unit area of 5 acres (i e , 23,333 m^2) was employed in this assessment For adults, the ingestion pathway contributes 55% to the SOR adjusted RSAL for depleted uranium, and 71 6% for enriched uranium For children, the ingestion pathway contributes approximately 70% for both depleted uranium and enriched uranium

7.3.2.3 RELATIVE CONTRIBUTIONS OF EXPOSURE VARIABLES

In probabilistic risk assessment, the probability distributions defined for input variables can be related to the variability in potential RSALs by using a variety of sensitivity analysis approaches As discussed in Section 7 3, the exposure variables that are likely to contribute most to variability in risk assessment are those that are a factor in a major exposure pathway, a factor in

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multiple exposure pathways, and are defined by a probability distribution with a high coefficient of variation Results are presented as tornado plots in Appendix H

Contributions to variance in the risk-based RSALs were evaluated by calculating normalized Spearman Rank correlation coefficients Since exposure duration satisfies each of the three criteria listed above, it can be expected that this variable will dominate the variance in the risk-based RSAL Appendix H, Tables H-1 to H-4 give tornado plots for americium and plutonium for the rural resident For americium, exposure duration accounts for approximately 94% of the variance in RSAL, whereas for plutonium, it accounts for approximately 84% For americium, no other exposure variable contributes more than 1% to variance For plutonium, the soil ingestion rate for children (9%) is ranked as the second most influential variable, followed by mass loading (3 5%) (see Appendix H) Probabilistic sensitivity analysis approaches were not applied to the dose-based calculations of RSALs Instead, RESRAD applies sensitivity analysis to the point estimate calculations, based on sensitivity ratios (see Section 4 3)

For uranium, the sensitivity analysis results are presented for individual radionuclides as tornado plots in Appendix H, Tables H-7 to H-14 Exposure duration contributes approximately 80% to variance for U-234 and U-238, and approximately 98% for U-235 The soil-to-plant transfer factor (transfer factor in this assessment, B_v and B_r in Baes et al , 1984) contributes approximately 13% to variance for U-234 Similarly, the various plant consumption rates contribute 1-2% to variance for U-234 In addition, exposure frequency contributes approximately 2% to variance for U-235 All other exposure variables are minor contributors to variance (e g , < 1%)

For the uranium non-cancer risk assessment, the probabilistic calculations yield a very different result since exposure duration is not a contributing factor to variance (i e , it cancels out of the risk equation) Soil ingestion rate for children and adults contributes 88% and 3% to variance, respectively Mass loading also contributes approximately 3%

7.3.2.4 Overall Impact of Variability on RME Value

Considered together, the probabilistic RME range and the sensitivity analysis provide insights regarding the relative importance of variability on the choice of the RME For risk-based estimates, the SOR approach is weighted towards the results for the RSAL calculations for plutonium Thus, the choice of RME may be more greatly impacted by the plutonium results as well For uranium, the ratios used to estimate total dose from depleted uranium and enriched uranium tend to weight U-234 and U-238 over U-235 The RME range is relatively narrow for all radionuclides and chemical toxicity (uranium, non-cancer) in this assessment (i e , factor of 3 or 4 between the 10th and 1st percentile RSALs) This result tends to support staying with the 95th percentile as the starting point for characterizing the RME

Similarly, the dose-based estimates yield narrow RME ranges for americium, plutonium, and uranium For the americium and plutonium RSALs, the dominant exposure pathway is soil ingestion, especially for the child rural resident For uranium, ingestion pathways also dominate the total dose

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For americium and plutonium together, the soil ingestion and inhalation exposure pathways together contribute nearly 70% to the total risk-based RSAL for the sum-of ratios case Thus, the variability associated with exposure variables in these pathways is most relevant The key variables are exposure duration, soil ingestion rate for children, and mass loading Although exposure duration is the most important variable in terms of contribution to variability in risk, childhood soil ingestion rate and mass loading also contribute 9% and 3 5%, respectively For uranium, the soil-to-plant transfer factors are also relatively important compared with the other exposure variables in the assessment, with the exception of exposure duration Uncertainty associated with the probability distributions for these variables is discussed further below

The point estimate RME value provides a different type of assessment, and is not expected to yield a similar result to the probabilistic approach The point estimate risk-based RSAL is lower than the 1st percentile from the probabilistic risk-based value Table 7-4 provides a closer comparison of the point estimates and probability distributions for the three key variables, illustrating that each point estimate corresponds to a relatively high percentile of the distribution Further information on uncertainty associated with the key variables discussed later can support this assumption A similar comparison is given in Table 7-2 for the Wildlife Refuge Worker scenario

Table 7-4 Comparison of point estimates and probability distributions for the highest ranked exposure variables identified for sensitivity analysis for plutonium – Rural Resident scenario

Exposure Variable	Probability Density Function (PDF)[1]	Point Estimate	
		Value	Percentile of PDF
Exposure duration (years)	Truncated lognormal (12 6, 16 2, 1, 87)	30	92 %ile
Soil ingestion, child (mg/day)	Truncated lognormal (47 5, 112, 0, 1,000)	200	96 %ile
Mass loading ($\mu g/m^3$)	Empirical distribution function (see Table 4-5)	67	95 %ile

[1]The same probability density function was used in the RESRAD 6 0 probabilistic simulations, converted to units for calculating annual dose Exposure duration is described as a one-year point estimate in RESRAD

7.4 IMPACT OF UNCERTAINTY IN EXPOSURE ON THE RSAL

Many of the point estimates and probability distributions used to calculate RSALs are based on the same data sets and share some of the same sources of uncertainty In addition, there is uncertainty in the assumptions that define each of the exposure scenarios in this assessment In general, the most important sources of uncertainty are likely to be paired with the exposure pathways and variables that contribute most to the variability in the RSAL This section presents a qualitative discussion and categorization of the uncertainties in the probabilistic analysis used to estimate RSALs Information on variability and uncertainty is presented together to facilitate the selection of an RSAL corresponding to the RME individual This discussion applies to both the dose-based RSALs using RESRAD and the risk-based RSALs using the Standard Risk equations, since the inputs to both models are based on essentially the same set of assumptions The intent of this qualitative assessment is to help both the decision makers and stakeholders

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decide whether the 5th percentile of the probability distributions for the RSALs most closely represents an RME receptor, or whether a more conservative percentile (1st to 5th percentiles) or less conservative percentile (5th to 10th percentiles) within the RME range may be justified and health protective Point estimates of the RME RSALs were also calculated for each scenario

General Procedure for the Qualitative Uncertainty Evaluation

(1) ***Confidence Rating of Parameter Uncertainty*** – In this qualitative evaluation of uncertainty, the working group focused on the exposure pathways and variables that most influenced a specific RSAL, and evaluated them in greater detail than the other factors The level of confidence in the probability distributions was evaluated by developing a confidence rating approach, modeled after the set of criteria developed by U S EPA to assess the weight of evidence for recommendations in the *Exposure Factors Handbook* (U S EPA, 1997) These criteria include study elements such as level of peer review, accessibility, reproducibility, focus on factor of interest, representativeness of study population, whether the study was primary data, currency, adequacy of data collection period, validity of approach, study size, characterization of variability, lack of bias in study design, and measurement error In addition, the studies were also evaluated against other criteria such as the number of other studies published using similar methodologies, and the degree of consensus among researchers on the reliability of the data This procedure resulted in a qualitative ranking of the confidence in the data as "high", "medium" or "low" For each exposure variable, the collective confidence ratings from the multiple criteria were evaluated to determine an overall, cumulative confidence rating for the specified probability distribution

(2) ***Model and Scenario Uncertainty*** – Other sources of uncertainty, either intrinsic to the assumptions in the RESRAD model and Standard Risk equations, or related to the exposure scenario, also contribute to the overall uncertainty of the RSAL estimates These sources of uncertainty were not necessarily identified as influential by the sensitivity analyses, but still contribute to the overall uncertainty of the RSAL estimates Professional judgment was used to evaluate the impact of these sources of uncertainty on the overall RSAL If a relatively conservative assumption was made due to the uncertainty, the RSAL corresponding to the RME is more likely to be protective

(3) ***Overall Impact of Uncertainty on the RME Value*** – Information on important sources of variability provides the context needed to determine the potential consequence of the sources of uncertainty (i e , parameters, models, and scenarios) The most influential sources of uncertainty will be associated with the pathways and variables that contribute most to variability in RSALs Application of this principle was used to estimate the overall impact of a particular pathway or variable on the RSAL for each individual radionuclide A graphical summary is used to jointly convey the sources of variability and uncertainty (see Figure 7-1)

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7.4.1 CONFIDENCE RATINGS FOR PARAMETER UNCERTAINTY

The overall confidence rating for each exposure variable characterized by a probability distribution is summarized in Table 7-5 (Rural Resident) and Table 7-6 (Wildlife Refuge Worker) The complete evaluation of each dataset is described in more detail in Appendix A Most of the variables received a rating of "medium" since they generally had a mix of both high and low ratings for specific elements of the available data Inhalation rates for children and adults are well studied and were assigned an overall rating of "high" The point estimates and distributions are based on studies that were well designed and focused on age-specific ventilation rates, and the data were developed for use in Monte Carlo simulations In addition, results were fairly consistent across studies Overall ratings of "low" confidence were assigned to the soil ingestion rate distribution for adults (due to limited available data) and consumption rates of grain (due to uncertainty about the homegrown fraction)

Exposure duration, which is the most influential exposure variable for the risk-based calculations, received a ranking of medium For the Rural Resident scenario, exposure duration refers to the residential occupancy period Extensive, well peer reviewed, national data exist to characterize variability in current residence times of respondents and residential mobility patterns, but there is uncertainty in extrapolating from these data to predict how much longer each respondent is likely to live in their residence For the Wildlife Refuge Worker, exposure duration refers to the occupational exposure period Representative data are available from surveys of biological workers, however, the sample size is small (i e , n = 20) (Ebasco, 1994) To compensate for this source of uncertainty, a relatively high upper truncation limit of 40 years was used to allow for future wildlife refuge workers to stay on site for more than five times the average reported exposure duration (seven years)

In addition, professional judgment was used to determine the relative level of conservatism and the impact of the point estimates used as inputs for those important variables (Table 4-4) for which insufficient data were available to develop distributions This information is discussed below and is shown in Tables 7-5 and 7-6

Table 7-5 Overall confidence ratings for exposure variables described with probability distributions for the Rural Resident scenario

Exposure Variable	Confidence Rating			Rationale	Appendix A[1]
	Low	Med.	High		
Exposure duration (risk only)		X		Large sample size and good concurrence among different study methodologies Uncertainty in combining mobility and mortality data to simulate total residence time, potential bias in national rather than regional data Lognormal distribution gives reasonable approximation to empirical distribution function, but truncation limit constrains the variance of the distribution by 25%	Table A-38
Exposure frequency		X		Large sample size, survey responses focus directly on time spent at home Uncertainty associated with characterization of variability, potential change in activity patterns since 1985, and potential error associated with 24-hour recall	Table A-35
Soil ingestion rate, child (IRs_child)		X		Variability over one week may overestimate variability over one year Uncertainty in mass balance methodology, and assumption associated with selection of probability distribution type and parameters Recent, primary data from representative population and moderate sample size	Table A-9
Soil ingestion rate, adult (IRs_adult)	X			Primary data but small sample sizes Repeat measurements over three-week period, although no attempt to quantify intra-individual variability Uncertainty in mass balance methodology given the number of days of negative ingestion rate estimates	Table A-7
Consumption rate, fruit, child (CR_f_child)		X		Large sample size and very good representativeness for vegetable and fruit, which comprise the majority of the total homegrown intake Uncertainty in homegrown fraction for grain Uncertainty in response survey bias, choice of probability distribution, independence of vegetable, fruit, and grain, and extrapolation to long-term average	Table A-15
fruit, adult (CR_f_adult)		X			
vegetable, child (CR_v_child)		X			
vegetable, adult (CR_v_adult)		X			
grain, child CR_g_child)	X				
grain, adult CR_g_adult)	X				

Exposure Variable	Confidence Rating			Rationale	Appendix A[1]
	Low	Med	High		
Mass loading		X		Difficult variable to predict given multiple influential factors Estimate based on site-specific data and conservative approach to weighting the probability of long-term average contributions of fire years	Sections A 1 9 2 and A 1 9 5
Soil-to-plant transfer factor for vegetative portion (TF_v) and reproductive portion (TF_r)		X		Large sample size and very good representativeness across soil types, plant types, and dry-to-wet weight conversion (DWC) factors Uncertainty in crop groupings to a single term, choice of lognormal probability distribution, and extrapolation of GSD estimates by plant types for 2/3 of data points	Section A 1 5 1
Inhalation rate, child (IRa_child)			X	Studies group inhalation rates by appropriate factors of age, gender, and activity Minute volumes reflect Canadian subjects, whereas activity pattern data is from U S subjects Consistently low coefficient of variation within studies	Table A-34
Inhalation rate, adult (IRa_adult)			X		

[1] See Appendix A for more detailed tables of confidence ratings and discussions of uncertainty for a wide range of study elements

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Table 7-6 Overall confidence ratings for exposure variables described with probability distributions for the Wildlife Refuge Worker scenario

Exposure Variable	Confidence Rating			Rationale	Appendix A[1]
	Low	Med.	High		
Exposure duration (risk only)		X		U S Fish and Wildlife survey of biological workers reported in Rocky Mountain Arsenal report Supplemental data for verification available from U S Bureau of Census, U S EPA, and National Center for Health Statistics review of National Survey Data Assumed to be a conservative (biased high) estimate of duration at the same job Uncertainty due to small sample size and extrapolation to upper truncation limit	Table A-43
Exposure frequency		X		Site data support intuition about employment patters during the year for full time workers Variance from three studies conducted by U S Fish and Wildlife is small, despite small sample size Uncertainty in truncation limits, especially on the low end	Table A-41
Soil ingestion rate, adult (IRs_adult)	X			Primary data but small sample sizes Repeat measurements over three-week period, although no attempt to quantify intra-individual variability Uncertainty in mass balance methodology given the number of days of negative ingestion rate estimates	Table A-7 and Section A 2 5 2
Mass loading		X		Difficult variable to predict given multiple influential factors Estimate based on site-specific data and conservative approach to weighting the probability of long-term average contributions of fire years	Sections A 1 9 2 and A 1 9 5
Inhalation rate, adult (IRa_adult)		X		Relevant study on biological workers used in Rocky Mountain Arsenal report Survey data of activity patterns combined with estimates of inhalation rate by activity Surrogate studies group inhalation rates by appropriate factors of age, gender, and activity Minute volumes reflect Canadian subjects, whereas activity pattern data is from U S subjects Consistently low coefficient of variation within studies	Table A-40

[1] See Appendix A for more detailed tables of confidence ratings and discussions of uncertainty for a wide range of study elements

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7.4.2 MODEL AND SCENARIO UNCERTAINTY

Unlike parameter uncertainty, which can be quantified based on the representativeness of the available data, sources of model and scenario uncertainty are generally more difficult to evaluate As described above, these sources of uncertainty may not contribute explicitly to the sensitivity analysis, but the methods used to account for these uncertainties may have important effects on the RSAL calculations Sources of uncertainty can generally be grouped into assumptions that affect all of the model calculations, and assumptions that are scenario-specific

Location of Exposure Units – A common source of uncertainty in future land use scenarios is the designation of the exposure unit It is difficult to specify where occupational or residential exposures may occur if structures are not yet built and residential plots are not specified Unless current buildings are used, which is not part of the current site plan, construction of new buildings would have to disturb the surface soil Any disturbance of contaminated surface soil would likely result in dilution and mixing The potential reduction in exposures resulting from the dilution or mixing of surface soils was not addressed in this assessment In addition, the entire contaminated zone available for inhalation exposure is assumed to be the base of a box, in which the receptor is uniformly exposed to dust, part of which is contributed from upwind clean dust as a function of annual average wind speed (directionally independent) This would be a conservative assumption in an area in which the wind favored one direction over others over time

Receptor Location – A simplifying assumption that is often applied in risk assessment is that individuals have equal probability of contacting any location within an exposure unit This assumption is particularly relevant for scenarios that include an external exposure irradiation pathway An area of contamination greater than a few hundreds of square meters, however, virtually saturates the external irradiation pathway, so that larger areas than this have little impact on the amount of irradiation experienced by the receptor Since the area of contamination used in the RESRAD analyses for the Pu and Am evaluations was 300 acres (i e , 1,400,000 m^2), all pathways, including the external radiation exposure pathway were saturated for scenarios in this assessment Therefore, each of the receptors was effectively modeled as always being in the middle of a large area of contamination This simplifying assumption is expected to be relatively conservative for areas that are outside the 903 Pad

Standard Risk Equation Approach – A number of simplifying assumptions are applied in the risk-based calculations of RSALs The risk equation does not take radioactive in-growth of americium or decay of both americium and plutonium over time into account Given that in-growth of americium and decay of americium and plutonium is mathematically predictable, the working group decided to model the situation where americium in-growth had reached its peak value (0 182 times the activity of plutonium), and to not take credit for exposure reduction through radioactive decay Because of the extremely long decay rates for uranium, this factor is not as important in the uranium assessment

Mass Loading – Section 4 6 and Table 6-4 provide an overview of the uncertainties associated with the development of a probability distribution for mass loading Simplifying assumptions that tend to yield a more conservative estimate include (1) the average particulate diameter is

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presumed to be one micron in diameter This assumption is likely to overestimate the total mass of inhaled particles that are available for absorption to the blood, and subsequently available for dose to other internal organs, (2) the concentration of radioactive contaminants in the dust is the same as the concentration in surface soil This assumption may overestimate the amount of inhalable radioactivity to some degree, (3) a weighted average of mass loading to account for the 10% probability of fire occurring in any one year is likely to overestimate the weighted average over longer time periods by as much as 100% over a 30 year exposure duration (see Appendix A for a quantitative analysis of this source of uncertainty), and (4) estimates of mass loading distributions do not take into account the influence of dilution from tilling, building construction or other invasive activities on long-term exposure, nor do the exposure estimates compensate for changes in habitability or crop production in the wake of a significantly large fire event Potential reductions in dust due to irrigation or the presence of roads are treated as insignificant

Overall, the assumptions used to define location of exposure unit and receptors, mass loading, and radioactive in-growth and decay are biased in a conservative direction and would support moving to a higher percentile in the RME risk range

7.5 IMPACT OF UNCERTAINTY IN THE CANCER SLOPE FACTORS AND DOSE CONVERSION FACTORS

Although not previously mentioned in the discussion of sensitivity, major sources of uncertainty in the risk and dose calculations in this evaluation are the cancer slope factors and the dose conversion factors used to relate exposures to risk and dose, respectively Indeed, uncertainty in the cancer slope factors and dose conversion factors have as significant an impact on the RSAL as exposure duration, since they are a factor in every exposure pathway Computation of these factors by the ICRP and EPA's Office of Radiation and Indoor Air, involved the use of models and parameters that introduced additional uncertainty into the tabulated coefficients

The sources of uncertainty in the risk coefficients taken from the HEAST tables may be generally grouped into one of three modeling components (1) the risk model, (2) the biokinetic model, or 3) the internal and external dosimetric models Uncertainties in the three modeling components are outlined in Sections 7 5 1 to 7 5 4 below A detailed discussion of these various sources appears in Federal Guidance Report 13 (FGR 13) (U S EPA, 1999a) Also refer to Section 4 7 (cancer slope factors) and Section 4 8 (dose conversion factors) for an overview of the values used in the analysis presented in this assessment The Office of Radiation and Indoor Air is currently tasked with quantifying estimates of uncertainty for a number of these sources (a task heretofore not undertaken), however the results of this work are not yet available

It is clearly outside the scope of the RSAL working group's expertise to deviate from the selection of risk and dose coefficients that have the endorsement of national and international bodies of experts Accordingly, the working group made conservative assumptions where alternative choices were available

7.5.1 RISK MODEL

Sampling variability – Estimates of radiogenic cancer risks are often based on a limited amount of epidemiologic data It has been estimated that there are less than 1,000 excess cancer deaths to date in the Japanese A-bomb survivor cohort, from which most of our risk estimates for the various cancer sites and age groups have been derived As a result, the number of excess cancers used to derive risk estimates for a particular cancer and age group can be small In general, the precision of risk estimates depends on the way epidemiologic data are grouped (e g , age, location, cancer site, radiation dose interval, etc) The discussion in FGR 13 (U S EPA, 1999a) indicates that, depending on the cancer site, the range of uncertainty (ratio of upper to lower 90% confidence values) is from about 1 6 for the types of cancer most often associated with plutonium internal exposure (bone and liver) up to four for colon cancer, and up to a factor of 10 for esophageal cancer It is not clear how this affects the total uncertainty of FGR 13 coefficients

Diagnostic misclassification – Two types of errors can occur detection errors (calling cancer cases something else) and confirmation errors (calling non-cancer cases cancer) Certain researchers have suggested that excess relative and absolute risk estimates should be adjusted upwards by about 15%, however this was not done in the computation of FGR 13 coefficients

Errors in dosimetry – Generally the basis for this uncertainty is in rethinking the dose response for the atomic bomb survivors who were primarily exposed to external gamma and neutron radiation A recent analysis (NCRP, 1997) suggested that current dose response models based on data from this cohort have overestimated the risk per unit dose, suggesting that the approach used in FGR 13 is conservative in this respect

Effects of radiation at low doses and dose rates – EPA policy still dictates the use of the linear no-threshold model for dose-response Although this model is under debate in the scientific community, the working group believes that this is the most appropriate model among alternatives and is reasonably conservative This conclusion is supported by the recommendations of several recent expert panels (UNSCEAR, 1993, 1994, NRPB, 1993, NCRP, 1997) that the linear no-threshold model for dose response is consistent with the current understanding of carcinogenic effects of radionuclides, and is justified for estimating risks from low doses of radiation

The cancer slope factors from FGR 13 (U S EPA, 1999a) or others recommended by EPA's Office of Radiation and Indoor Air are central estimates from the linear no-threshold model of the age-averaged, lifetime radiation cancer risk for incidence of both fatal and nonfatal cancers The central estimate value from this model is used as the cancer slope factor for radionuclides based on the high confidence associated with the radionuclide database

Relative biological effectiveness (RBE) for alpha particles – EPA used a value of 20 for the RBE for alpha particles (as recommended by ICRP) for low dose rates (the area of interest for environmental exposures) This is consistent with central tendency estimates for combined research data on solid tumor induction by alpha particles and fission neutrons The observed range of RBE in this data is from 5 to 60

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Transporting risk estimates across populations – Much of the risk model epidemiological data is taken from the Japanese population, which is known to have substantially higher stomach cancer rates, and lower lung, colon and breast cancer rates than the United States population Land and Sinclair (1991) presented two different relative risk models for transporting estimates derived from the Japanese A-bomb survivor data Given that it is not clear how to adjust risk estimates across such populations, EPA constructed a model that yields risk estimates that are in between the risk estimates that would be calculated through application of the two Land and Sinclair models

Age and time dependence of risk per unit dose – There is still considerable uncertainty in estimating the risk of solid tumor formation in individuals exposed to radiation before age 20, and yet the highest relative cancer risks appear in the youngest exposure categories

Site-specific cancer morbidity risk estimates – Current risk estimates do not reliably adjust for long term survival of cancer cases based on the success of current and future treatment modalities This is less important to this assessment than other sources of uncertainty, since all risk derived RSALS are based on cancer incidence rather than mortality

7.5 2 BIOKINETIC MODEL FOR PLUTONIUM

Chemical form of plutonium and selection of lung absorption type – DOE and the other agencies had differing opinions on the degree of confidence in the chemical form of plutonium contamination in the environment at Rocky Flats In the interest of prudence, the decision was made by the working group to select the most conservative choice for lung absorption type (Type M)

Particle size distribution and deposition in respiratory system – The RESRAD model assumes that the input parameter for the annual average value of mass loading in air represents a distribution of particles of one micron in diameter This results in a likely overestimate of the dose to the lung, absorption to the blood, and subsequent dose to other internal organs

Lung dose over broad range of Absorption Type M – It is unlikely that the rate of absorption of material inhaled at Rocky Flats is at the rapid end of the range, since most of the material is probably in relatively insoluble forms However the difference in overall dose between the S and M absorption types is slight (a few percent), owing to the relative unimportance of the inhalation pathway Type M is clearly a more conservative choice, although only slightly so

Precision in determination of gastrointestinal uptake fraction (f1) – Use of the ingestion dose and risk coefficients from ICRP 72 (ICRP, 1996) / FGR 13 (U S EPA, 1999a) assures that the f1 value for the less soluble forms of plutonium at Rocky Flats is conservative The values are approximately 50 times higher than that used for plutonium oxides in ICRP 30 (ICRP, 1979), and ICRP 68 (ICRP, 1994b) (worker exposure)

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7.5.3 INTERNAL DOSIMETRIC MODELS FOR PLUTONIUM

The literature contains a broad range of estimated residence times of plutonium on bone surfaces The dose impact of bone exposure is believed to be insignificant compared to lung, liver, and GI tract dose

Dose to the colon wall from plutonium in colon contents may be important to ingestion dose and risk estimates The recommended value of 1% of ingested material emitting alpha radiation that strike the wall of the colon is believed to be conservative See FGR 13 (U S EPA, 1999a), and Appendix D

7.5.4 EXTERNAL DOSIMETRIC MODEL FOR PLUTONIUM

There is high uncertainty in the estimates of transport and dose from very low energy photons However, in this analysis, the uncertainty contribution is considered insignificant for plutonium dose and risk calculations, owing to the very small contribution of external exposure to dose and risk from plutonium photons

The working group believes that the dose coefficients, which incorporate uncertainty from the biokinetic and internal dosimetry sources cited below, are selected conservatively The risk coefficients incorporate additional and possibly greater uncertainty from the use of the risk model, for which not all sources of uncertainty have been conservatively addressed However, the working group's decision to model both dose and risk serves as a check on the impact of uncertainty in the risk model The consistency that is observed between RSALs computed on the basis of dose and on the basis of risk suggests that the working group's approach is reasonable Assumptions used to select the models appear to be relatively neutral in their influence on the choice of the RME value

7.6 OVERALL IMPACT OF VARIABILITY AND UNCERTAINTY ON THE SELECTION OF THE RME VALUE

The previous sections have described the impact of variability and uncertainty in the major exposure pathways, major exposure variables, and choice of models and scenarios used in the RSAL calculations Table 7-7 and 7-8 summarize the overall confidence in the exposure pathways and assumptions associated with the inputs to the Rural Resident and Wildlife Refuge Worker probabilistic risk assessments The majority of variables have a high or medium confidence rating suggesting that an RSAL value between the 10^{th} and 5^{th} percentiles should be selected as representative of the RME at this site Figure 7-1 shows how the information from the sensitivity analysis (variability) can be combined with the confidence ratings (uncertainty) The majority of the variables that contribute most to the variability in RSAL (e g , exposure duration, soil ingestion rate) also have a medium confidence rating Similarly, those variables with relatively low confidence ratings also appear to be minor contributors to variability Conclusions regarding model and scenario uncertainty also suggest the selection of an RSAL value between the 10^{th} and 5^{th} percentile would be appropriate Overall, the working group recommends that an RSAL value between the 10^{th} and 5^{th} percentiles be selected as representative of the RME at the Rocky Flats site

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Table 7-7 Rural Resident scenario RSALs (relevant to all radionuclides) – the impact of confidence ratings on the percentile of the RME range (10^{th} to 1^{st} percentiles) that represents the RSAL

Exposure Pathways and Variables	**Confidence Rating for PDF**	**Professional Judgment**	**Impact on RME Percentile**		
			1^{st} – 5^{th} %ile	5^{th} %ile	5^{th} – 10^{th} %ile
Variables in All Exposure Pathways (except food ingestion)					
Exposure duration	PDF - Medium	Conservative Based on national database			X
Exposure frequency	PDF - Medium	Realistic Based on national database		X	
Indoor time fraction	Point estimate	Realistic Set at 85% of time on-site, which is approximately the 75^{th} percentile for U S residents, so that indoor time fraction plus outdoor time fraction would add up to 1 0 (*Exposure Factors Handbook*, U S EPA, 1997)		X	
Outdoor time fraction	Point estimate	Realistic Set at 15% of time on-site, which is approximately the 75^{th} percentile for U S residents, so that indoor time fraction plus outdoor time fraction would add up to 1 0 (*Exposure Factors Handbook*, U S EPA, 1997)		X	
External Exposure					
Gamma shielding factor	Point estimate	Conservative EPA default (*Soil Screening Guidance for Radionuclides User's Guide,* U S EPA, 2001)			X
Thickness of contaminated zone	Point estimate	Realistic Set at 15 cm, site-specific data indicates that 90% of Pu-239 and Am-241 is within this thickness		X	
Density of contaminated zone	Point estimate	Conservative Set at 1 7 g/cm^3, site-specific average for Rocky Flats alluvium that largely includes data from sampling depths greater than 15 cm The more dense the soil, the more activity per volume of soil and the greater the potential dose due to external irradiation At the same time, as soil becomes more dense the attenuation of external radiation from below the surface increases		X	

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Exposure Pathways and Variables	Confidence Rating for PDF	Professional Judgment	Impact on RME Percentile		
			1^{st} – 5^{th} %ile	5^{th} %ile	5^{th} – 10^{th} %ile
Food Ingestion					
Fruit, vegetable, and grain consumption	PDF - Medium, (fruits and vegetables), Low (grains)	Realistic Based on national database, taking age, seasonal homegrown consumption rates for the West into account		X	
Depth of roots	Point estimate	Conservative Set at 15 cm in order to limit root uptake to maximally contaminated zone Most vegetable garden roots do not exceed this depth			X
Depth of soil mixing layer	Point estimate	Conservative Set at 15 cm, equal to the thickness of the contaminated zone, maximizing the availability of contaminated material for resuspension			X
Thickness of contaminated zone	Point estimate	Realistic Set at 15 cm, site-specific data indicates that 90% of Pu-239 and Am-241 is within this thickness		X	
Soil-to-plant transfer factor	Point estimate (Am and Pu) PDF - Medium (uranium)	Conservative Point estimates for Am-241 and Pu-239 developed by Whicker et al (1999) are lower than older values, Distribution for U-234, U-235, and U-238 is based on a large data set and is representative across soil types, plant types, and dry-to-wet weight conversion factors			X
Contaminated fraction, homegrown foods grown on contaminated soil	Point estimate	Conservative Set at 1 0 All homegrown foods were assumed to be grown on contaminated soil			X
Soil ingestion					
Soil ingestion rate, child	PDF - Medium	Realistic, based on best estimates from Anaconda study This study used 250 micron sieved soil, was probably more representative of Western soils and populations, and used a greater proportion of the data		X	
Soil ingestion rate, adult	PDF - Low	Rough estimate of variability based on two pilot studies with small sample sizes	X		

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Exposure Pathways and Variables	Confidence Rating for PDF	Professional Judgment	Impact on RME Percentile		
			1st – 5th %ile	5th %ile	5th – 10th %ile
Thickness of contaminated zone	Point estimate	Realistic Set at 15 cm, site-specific data indicates that 90% of Pu-239 and Am-241 is within this thickness		X	
Soil mixing layer	Point estimate	Conservative Set at 15 cm, equal to the thickness of the contaminated zone, maximizing the availability of contaminated material for resuspension			X
Overall Impact on Probabilistic RSAL[2]			**1**	**9**	**7**

[1]High uncertainty would support a more conservative RSAL (i e , lower percentile, in the 1st to 5th %ile category) whereas low uncertainty would support a less conservative RSAL (i e , higher percentile, in the 5th – 10th %ile category) The 5th percentile is the starting point for determining the RSAL from a probabilistic assessment
[2]The sum of the X's in each category gives an indication of the overall impact of uncertainty on the choice of the RME percentile, assuming equal weighting/relevance of each category presented

Table 7-8 Wildlife Refuge Worker scenario RSALs (relevant to all radionuclides) – the impact of confidence ratings on the percentile of the RME range (10^{th} to 1^{st} percentiles) that represents the RSAL

Exposure Pathways and Variables	Confidence Rating for PDF	Professional Judgment	Impact on RME Percentile		
			1^{st} – 5^{th} %ile	5^{th} %ile	5^{th} – 10^{th} %ile
All Exposure Pathways					
Indoor time fraction	Point estimate	Realistic Assumes that half of the work day will be spent indoors		X	
Outdoor time fraction	Point estimate	Realistic Assumes that half of the work day will be spent outdoors		X	
Exposure time	Point estimate	Realistic Assumes an 8 hour work day		X	
Exposure duration	PDF - Medium	Conservative Distribution fit to mean and SD reported from U S Fish and Wildlife survey of biological workers (n=80) Truncated normal distribution biases the mean higher by 2 years to 9 and the SD lower by 1 5 years to 5 6			X
Exposure frequency	PDF - Medium	Realistic U S Fish and Wildlife survey (n=33) yields similar estimates of CTE and RME as national data from Bureau of Labor Statistics		X	
Soil Ingestion					
Soil ingestion rate, adult	PDF - Low	Rough estimate of variability based on two pilot studies with small sample sizes	X		
External Exposure					
Gamma shielding factor	Point estimate	Conservative EPA default (*Soil Screening Guidance for Radionuclides User's Guide,* U S EPA, 2001)			X
Thickness of contaminated zone	Point estimate	Realistic Set at 15 cm, site-specific data indicates that 90% of Pu-239 and Am-241 is within this thickness		X	
Soil mixing layer	Point estimate	Conservative Set at 15 cm, equal to the thickness of the contaminated zone, maximizing the availability of contaminated material for resuspension			X

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Exposure Pathways and Variables	Confidence Rating for PDF	Professional Judgment	Impact on RME Percentile		
			$1^{st} - 5^{th}$ %ile	5^{th} %ile	$5^{th} - 10^{th}$ %ile
Density of contaminated zone	Point estimate	Conservative Set at 1 7 g/cm^3, site-specific average for Rocky Flats alluvium that largely includes data from sampling depths greater than 15 cm The more dense the soil, the more activity per volume of soil and the greater the potential dose due to external irradiation At the same time, as soil becomes more dense the attenuation of external radiation from below the surface increases		X	
Inhalation					
Average annual wind speed	Point estimate	Realistic Site-specific data		X	
Inhalation rate, adult	PDF - Medium	Realistic Minute volumes were not measured directly, however, a site-specific activity pattern data were incorporated		X	
Mass loading for inhalation	PDF - Medium	Conservative Probability of prairie fire conservatively incorporated, using projected prescribed burn frequency and site-specific mass loading measurements from the site-specific wind tunnel studies		X	
Indoor dust inhalation shielding factor	Point estimate	Conservative Set at 0 7 to account for windows being open during the warm months This value exceeds EPA default of 0 4		X	
Depth of soil mixing Layer	Point estimate	Conservative Set at 15 cm, equal to the thickness of the contaminated zone, maximizing the availability of contaminated material for resuspension			X
Thickness of contaminated zone	Point estimate	Realistic Set at 15 cm, site-specific data indicates that 90% of Pu-239 and Am-241 is within this thickness		X	
Overall Impact on Probabilistic RSAL[2]			1	11	4

[1]High uncertainty would support a more conservative RSAL (i e , lower percentile, in the 1^{st} to 5^{th} %ile category) whereas low uncertainty would support a less conservative RSAL (i e , higher percentile, in the $5^{th} - 10^{th}$ %ile category) The 5^{th} percentile is the starting point for determining the RSAL from a probabilistic assessment
[2]The sum of the X's in each category gives an indication of the overall impact of uncertainty on the choice of the RME percentile, assuming equal weighting/relevance of each category presented

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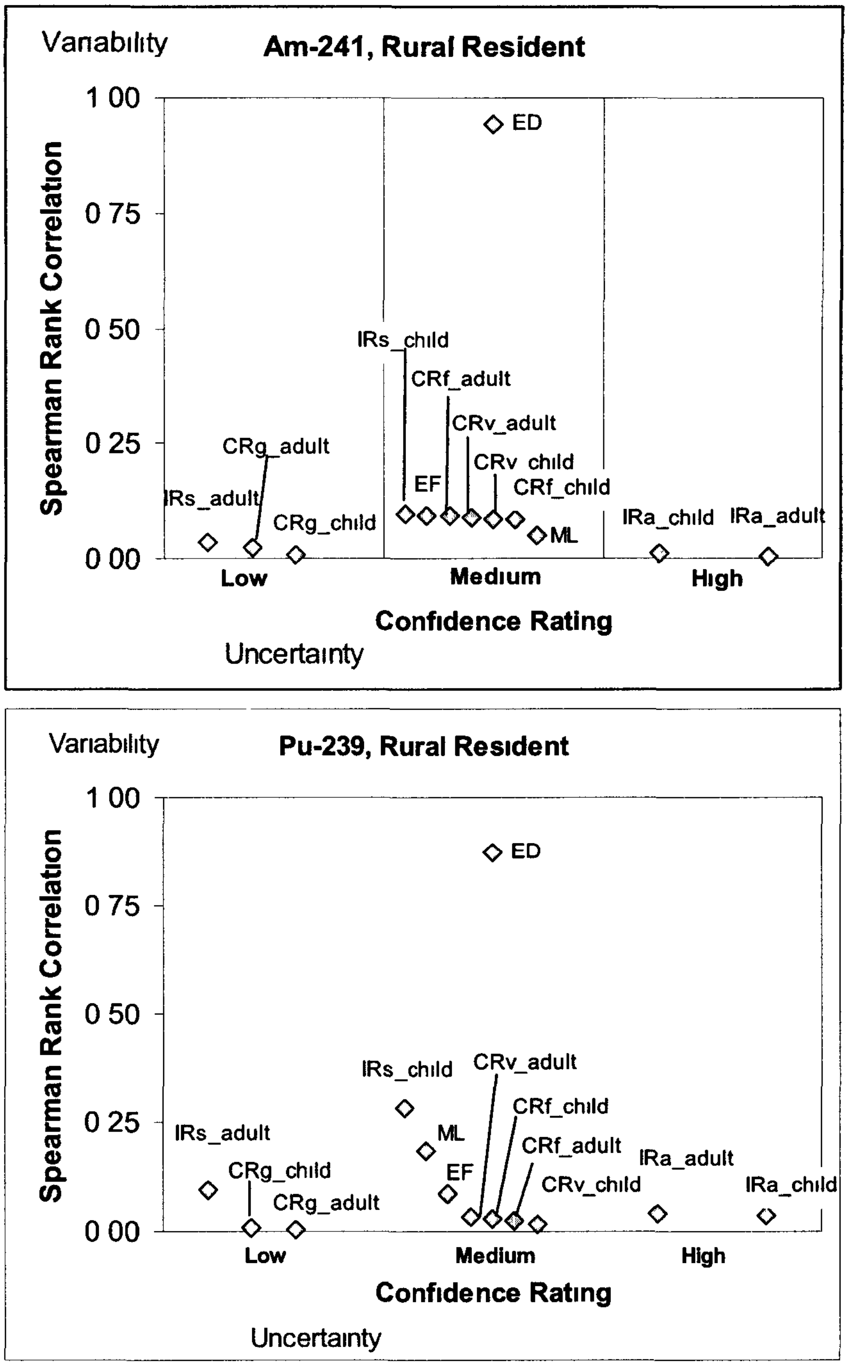

Figure 7-1 Relative importance of exposure variables based on contributions to variability (Spearman Rank correlation coefficients) and uncertainty (confidence ratings) for Am-241 and Pu-239

Age-group specific variables are given by "child" or "adult" ED = exposure duration, EF = exposure frequency, ML = mass loading, IRs = soil ingestion rate, CRf = consumption rate of fruit, CRv = consumption rate of vegetables, CRg = consumption rate of grain, IRa = inhalation rate]

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APPENDIX A
JUSTIFICATION AND SUPPORTING DOCUMENTATION FOR THE INPUT VARIABLES

This appendix documents the rationale for the selection of values that were used in performing Residual Radioactivity Model (RESRAD) and Environmental Protection Agency (EPA) Standard risk model runs for the 2002 radionuclide soil action level (RSAL) determinations The RSALs for the rural resident and wildlife refuge worker were estimated using both a probabilistic and a point estimate approach All probabilistic risk simulations were run with 10,000 iterations using Crystal Ball® version 5 1 (Decisioneering, 1986)The RSALs for the office worker and open space user were estimated using only a point estimate approach A probabilistic assessment was not performed for these two exposure scenarios because they are not expected to have a significant impact on the risk decision-making process for this site Since the development of a probabilistic assessment can be very time and resource intensive, the working group made a decision to focus their efforts on developing the probabilistic assessments for the Rural Residential and Wildlife Refuge Worker scenarios

A.1 EXPOSURE VARIABLES FOR THE RURAL RESIDENT SCENARIO

Table A-1 Variables described by a probability distribution in the Rural Resident scenario

• Soil Ingestion Rate	• Exposure Duration
• Plant Ingestion Rate, Homegrown	• Mass Loading Factor
• Inhalation Rate	• Soil-to-Plant Transfer Factor
• Exposure Frequency	

A.1.1 SOIL INGESTION RATE FOR ADULTS (AGES 7+ YEARS)

The soil ingestion rate variable represents the average daily mass of soil or dust that enters the human gastrointestinal tract For adults, soil ingestion is thought to reflect a combination of direct ingestion from materials placed in the mouth (e g , hands, food, cigarettes) or indirectly via inhalation when larger particles are transferred from the upper respiratory tract to the mouth (via mucociliary transport) and ingested

It is generally accepted that daily activities patterns may be an important factor affecting ingestion rates EPA *Risk Assessment Guidance* (U S EPA, 1991a) differentiates between soil and dust contact intensive activities, in which adults are in heavy contact with soils and dusts on a regular basis (e g , construction worker), and non-contact intensive activities such as the typical homeowner, office worker, or professional However, very little data are available from which to quantify soil ingestion rates among adults for either category of activities Therefore, the estimate for soil ingestion rate discussed below is considered to be equally applicable for each of the residential/occupational land use scenarios considered in the Rocky Flats risk assessment

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A.1.1.1 PROBABILITY DISTRIBUTION FOR THE ADULT RURAL RESIDENT

This report recommends the following probability distribution for use in Standard Risk equations that are based on EPA's *Risk Assessment Guidance* (U S EPA, 1989) in order to characterize *interindividual* variability in adult soil ingestion rate

IRs_adult ~ Uniform (0, 130) mg/day

The uniform distribution is defined by two parameters

- minimum 0 mg/day
- maximum 130 mg/day

For the RESRAD model, the same distribution can be used by converting the units from (mg/day) to (g/yr)

- minimum 0 mg/day x 0 001 g/mg x 365 day/yr = 0 g/yr
- maximum 130 mg/day x 0 001 g/mg x 365 day/yr = 47 45 g/yr

Therefore, applying the same assumptions as the Standard Risk equations, the equivalent distribution for the adult rural resident for use in RESRAD is

IRs_adult ~ Uniform (0, 47.45) g/yr

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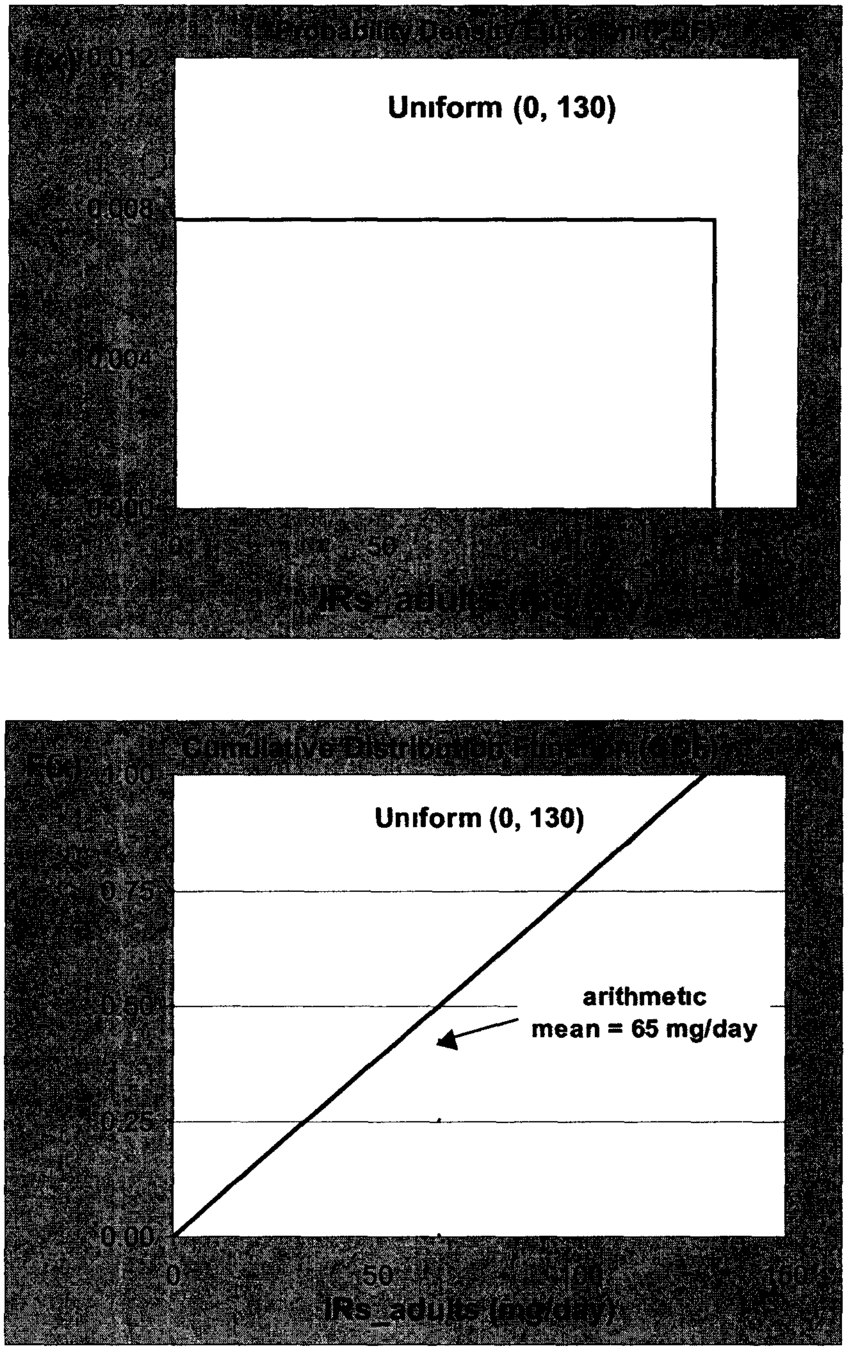

Figure A-1 Probability density function and cumulative distribution function views of the uniform distribution for adult soil ingestion rate (mg/day)

A.1.1.2 JUSTIFICATION FOR ADULT SOIL INGESTION INPUT VARIABLE

The limited data available on soil ingestion rates in adults poses a challenge when attempting to develop a probability distribution that characterizes interindividual variability The following discussion provides highlights of the available empirical data, and an overview of the reasoning used in developing the recommended distribution

Empirical data on adult soil ingestion rates are available from two studies (Calabrese et al , 1990, Calabrese et al , 1997a), each conducted concurrently with a study of childhood soil ingestion rates The 1990 study was conducted in Amherst, MA, while the 1997 study was conducted in Anaconda, MT The purpose of these pilot studies was to verify the tracer mass balance methodology used in the child studies, rather than to investigate the amount of soil normally ingested by adults Nevertheless, as indicated by the authors, it does offer an estimate of the amount of soil ingested by the adult subjects in the study over a period of several consecutive days for each of three or four weeks With the mass balance methodology, soil ingestion is estimated by subtracting the quantity of trace element in food and soil capsules from the total amount excreted in feces For both studies, the soil capsules administered to subjects contained different amounts of soil obtained from the same soil library, originally collected from locations in Amherst, MA

A more detailed summary of the best tracer methodology used to estimate soil ingestion rates is given in the discussion on the probability distribution developed to characterize soil ingestion rates in children in this Appendix A Stanek and Calabrese (1995a) recommend estimating a distribution of soil ingestion rates from this type of study based on the median of the best tracers for each subject week On the basis of percent recoveries, the four best tracers were determined to be aluminum, silicon, yttrium, and zirconium for the 1990 study, and the same set plus titanium for the 1997 study Results of the 1990 study reported by week and tracer are given in Table A-2

Table A-2 Calabrese et al , 1990 (Table 7, p 93) study results by week and tracer element based on median Amherst soil concentrations Statistics are the mean/median ingestion rates among n = 6 subjects

Study Week	**Soil Ingestion (mg/day) by Tracer [mean/median]**			
	Al	**Si**	**Y**	**Zr**
1	110 / 60	30 / 31	63 / 44	134 / 124
2	98 / 85	14 / 15	21 / 35	58 / 65
3	28 / 66	-23 / -27	67 / 60	-74 / -144

The data may also be grouped by individual and tracer element, and averaged across all three weeks, as shown in Table A-3 Corresponding estimates for each of the six individuals are given in Figure A-2

Table A-3. Calabrese et al , 1990 (Table 8, p 94) study results by individual and tracer element based on median Amherst soil concentrations [for n = 3 weeks] Also see Figure A-2

Subject Statistics	Soil Ingestion (mg/day) by Tracer				Arithmetic Mean of 4 Tracers	Median of 4 Tracers
	Al	Si	Y	Zr		
minimum	1	7	27	17	19	22
maximum	173	99	111	216	133	117
mean	77	5	53	33	63	55
median	57	1	65	-4	54	36
standard deviation	65	55	51	141	42	39

[1]Statistics include negative estimates, which are an indication of the measurement error associated with mass balance fecal tracer studies, 3/6 estimates were negative for Si and Zr while 1/6 was negative for Y, as shown in Figure A-2

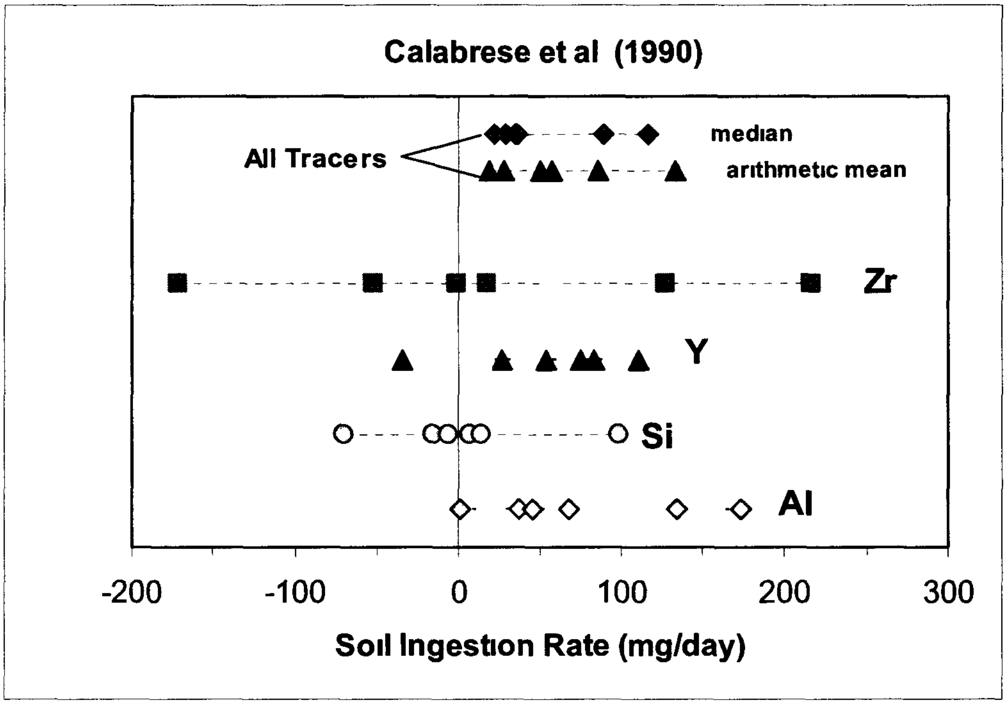

Figure A-2 Calabrese et al (1990) results for four best tracers showing three week average estimates for each of n = 6 individuals Summary statistics (median, AM) across trace elements are also shown Summary statistics across individuals are given in Table A-3

For the three weeks of data (Table A-2), the minimum, non-negative average soil ingestion rate (i e , averaged across all six subjects) is given by Si (14 mg/day), while the maximum is given by Zr (134 mg/day) For the six subjects (Table A-3), the minimum, non-negative average soil ingestion rate (i e , averaged across all three weeks) is given by Al (1 mg/day), while the

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maximum is given by Zr (216 mg/day) If the estimates are further averaged across individuals (including negative estimates), the mean soil ingestion rate ranges from 5 to 33 mg/day, while the median ranges from -4 to 65 mg/day

A more informative metric of interindividual variability may be to combine the trace element concentrations by individual As shown in Figure A-2, the AM and median soil ingestion estimates for n = 6 subjects ranges from 19 to 133 mg/day and 22 to 117 mg/day, respectively

Calabrese et al (1997a) provide a second set of pilot study data for comparison to the Calabrese et al (1990) data This study was conducted with n = 10 subjects over a four week period using capsules with the same soil as the 1990 study (Amherst), but a different geographic location for incidental soil ingestion (Anaconda) The authors focus on uncertainties associated with particle size, highly variable food/soil transfer factors across trace elements for a subject-day, and distinction between soil and dust ingestion

Data were presented in a slightly different format than the 1990 study, making direct comparisons difficult In the 1997 study, selected statistics of the average daily non-capsule soil ingestion among 10 adults are given by study week (1 to 4), rather than by subject and week Data were limited to 5 of 8 trace elements (Al, Si, Ti, Y, and Zr) for which concentrations were found to be homogeneous across different particle sizes Results of the 1997 study by week and tracer are given in Table A-4 Table A-5 and Figure A-3 provide additional summary statistics for Week 1, when no soil capsule was administered

Table A-4 Calabrese et al (1997a) (Table 4, p 251) study results by week and tracer element based on median Amherst soil concentrations Statistics are the mean/median among n = 10 subjects for each week

Study Week[1]	Soil Ingestion (mg/day) by Tracer [mean/median]				
	Al	Si	Ti	Y	Zr
1	12 / 5	-20 / -24	100 / 126	187 / -40	-11 / -25
2	20 / 14	-7 / -3	708 / 358	219 / 69	-31 / -43
3	22 / 38	31 / -1	1013 / 251	414 / 159	9 / -37
4	-115 / -93	-127 / -108	132 / 19	84 / 197	-350 / -342

[1]Mass of soil administered in capsules week 1 0 mg/day, week 2 20 mg/day, week 3 100 mg/day, week 4 500 mg/day

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Table A-5. Calabrese et al (1997a) (Table 4, p 251) study results by tracer element for week one [no soil capsule] Also see Figure A-3

Subject Statistics	Soil Ingestion (mg/day) by Tracer				
	Al	Si	Ti	Y	Zr
Minimum	-21	-59	-1969	-376	-81
Maximum	67	64	1240	2059	133
Mean	12	-20	100	187	-11
Median	5	-24	126	-40	-25
Standard dev	31	37	876	707	57

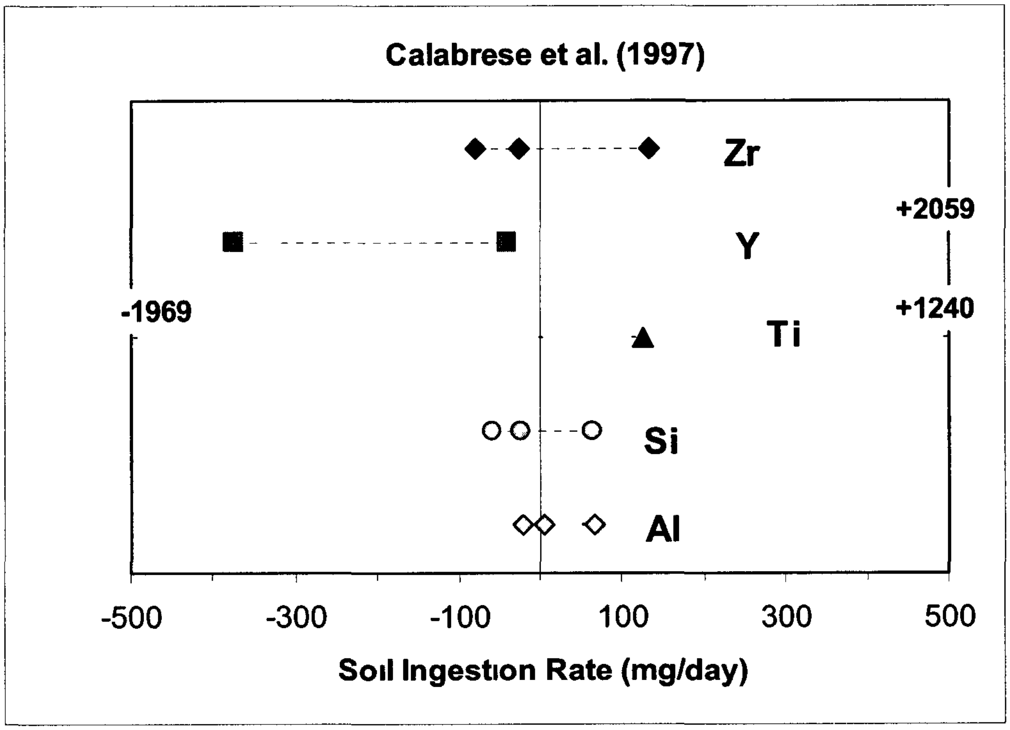

Figure A-3 Calabrese et al (1997a) results for five best tracers showing (min, median, max) of average estimates for n = 10 individuals during week one Summary statistics are given in Table A-5

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Table A-6 Calabrese et al (1997a) (Table 9, p 255) study results for 10 adults overall (Anaconda) and for four weeks, using trace elements Al, Si, Ti, Y, and Zr with the lowest food/soil ratio on any given subject-day Also see Figure A-4

Statistics	Soil Ingestion (mg/day) by Best Tracer				
	Med 4[1]	Best[2]	2nd	3rd	4th
minimum	-400	-452	-410	-835	-753
maximum	620	1177	2473	1039	6353
mean	6	136	99	-8	189
standard dev	165	308	561	314	1074
5th %ile	-189	-144	-318	-443	-398
25th %ile	-55	-31	-46	-102	-73
50th %ile	-11	21	-5	-11	-9
75th %ile	34	305	43	55	62
95th %ile	331	797	1362	654	1317

[1]Median soil ingestion rate among the four best trace elements on each subject-day
[2]Frequency of best tracers for 40 subject-weeks Al (42%), Si (10%), Ti (25%), Y (20%), and Zr (3%)

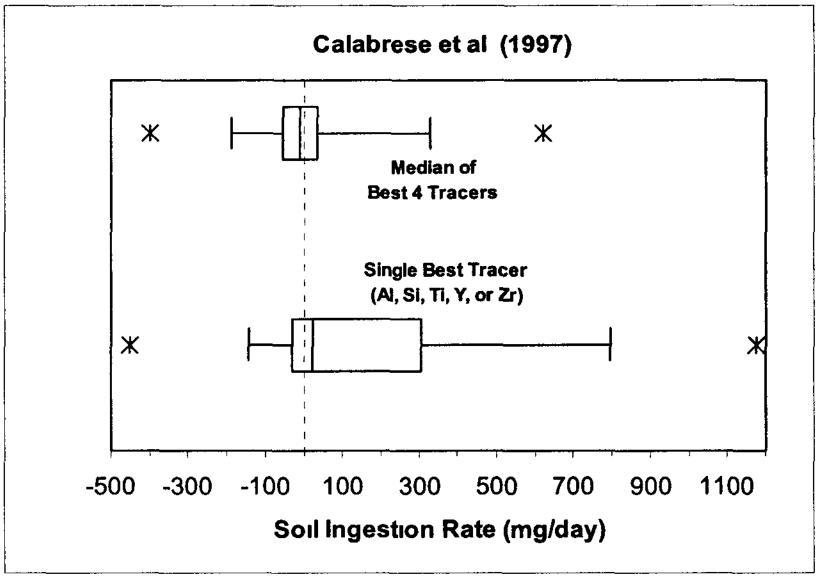

Figure A-4 Calabrese et al (1997a) results for median of four best trace elements and the single best trace element on each subject-day Box and whisker plots represent distributions for interindividual variability based on 10 subjects with soil ingestion rates averaged over four weeks Summary statistics are given in Table A-6

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The 1997 study also presents selected statistics for the distribution of soil ingestion rates using different combinations of trace elements for any given subject day Table A-6 and Figure A-4 provide the results for the median of the best trace elements and the single best trace element on each subject-day

An uncertainty associated with both studies is the calculation of negative ingestion rates on many subject-days Negative ingestion rates occur due to complexities in the tracer mass balance methodology, such as the assumed transit time in the GI tract and the non-soil sources of tracer elements For the 1990 study, the trace element with the most variable results (given by the reported SD in Table A-3) is Zr (SD = 141 mg/day), while the least variable is Si (SD = 55 mg/day) The distribution of ingestion rates by individual is more clearly shown in Figure A-2 For the 1997 study (Figure A-3), the most variable soil ingestion estimates during week one are given by Ti (SD = 876), while the least variable is Al (SD = 31) The authors conclude that the broad range in estimates for different trace elements implies that a simple average estimate (over all trace elements) provides little insight into adult soil ingestion since estimates based on different trace elements for the same adults and time periods are so highly variable (Calabrese et al , 1997) An alternative approach based on the "best" trace element for any given day still yields a negative ingestion rate for nearly half of the study weeks

Basis for Uniform (0, 130) Distribution – Based on the small sample sizes and the prevalence of negative ingestion rates, no attempt was made to evaluate a variety of probability distributions for either study The range of plausible ingestion rates for adults varies depending on which trace elements are examined The 1990 study suggests that ingestion rates averaged over a three-week period may vary from a minimum of less than 1 mg/day (truncating negative values to 0) to a maximum of 216 mg/day (for Zr) When results for individual trace elements are combined by calculating a simple/arithmetic mean or median for each subject, the plausible range across subjects is approximately 20 to 130 g/day

The 1997 study suggests that interindividual variability may be even greater than that of the 1990 study When trace element results are combined by calculating the median of the four best tracers on any subject-day, the plausible range is [– 400 mg/day to + 620 mg/day], with 5th and 95th percentiles [–189 mg/day, 331 mg/day] For individual trace element results (e g , best tracer for each of 40 subject-weeks), the frequency of selection of trace elements ranged from a high of 42% of subject-weeks for Al to a low of 3% for Zr Ti (25%), Y (20%), and Si (10%) give intermediate contributions If the most variable of the trace elements are excluded from the analysis (Y and Ti), the results of the individual trace element concentrations suggest a plausible range that is more similar to the 1990 study For example, the maximum values for Al, Si, and Zr are 67, 64, and 133 mg/day, respectively

One of the limitations in empirical data such as soil ingestion rate data is that measurements over a short time period (i e , weeks) are used to estimates long-term average behavior Typically, interindividual variability measured over a period of days or weeks will overestimate variability over an one-year period or longer This is because most individuals will tend to experience a wide range of conditions over a long time period (e g , years), and very high (or low) estimates measured during one week are likely to be offset by different exposures the next This process is sometimes referred to as "averaging towards the mean", and presents a major challenge in

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applying short-term survey data to risk assessments A reasonable assumption is that the plausible range of soil ingestion rates offered by these two studies is more extreme (i e , conservative) than may be necessary

Conversely, the fact that the sample sizes are small suggests that there is a good chance that the true range of soil ingestion rates among the population has not been measured The intent in using a uniform distribution to describe interindividual variability is not to represent the range (minimum and maximum) of ingestion rates in a statistical sense (i e , the individuals with the extreme lowest and highest ingestion rates) Rather, the goal is to characterize a range of long-term average ingestion rates that includes the RME individual

A range of 0 to 130 mg/day was selected based on professional judgment Since negative ingestion rates are reasonable results given the uncertainty in the mass balance methodology, but unreasonable as inputs to an exposure model, 0 mg/day was selected as the plausible minimum value The maximum of 130 mg/day is greater than 80% of the individual trace element results for the 1990 study, and approximately equal to the maximum value when trace element results are averaged for each individual Similarly, the maximum of 130 mg/day is greater than approximately 80% of the results in the 1997 study based on the "median of four best tracers" approach, and is equal to or greater than three of five single tracer results for Al, Si, and Zr For the remaining two trace elements, Ti and Y, the standard deviations are very high (876 and 707 g/day, respectively) The low frequency of selection of these tracers as "best" tracer elements for the 40 subject weeks (see Table A-6, footnote 2) suggests that this high variability has more to do with measurement error than with inherently high interindividual variability in soil ingestion

Given a plausible range, but no further information regarding the shape or spread of the distribution (e g , mean, SD), a uniform distribution was selected A uniform distribution assigns equal probability to any value within the range, rather than weighting certain values by ascribing a nonuniform shape This can be contrasted with a normal or lognormal distribution, for which values at the tails of the distribution are much less likely than those nearer to the mean or median For example, if a lognormal distribution was selected with a mean of 57 mg/day and SD of 65 mg/day (loosely based on results for aluminum in the 1990 study), an ingestion rate of 100 mg/day would be the 86th percentile of the distribution (i e , less than 15% of values are expected to be greater than 100), whereas with the uniform distribution, nearly one-fourth (25%) of the values are expected to be greater than 100 mg/day In general, compared with a uniform distribution, the use of an untruncated lognormal distribution can be expected to yield lower values in the central, or mid-percentiles of the distribution, and higher values in the upper tail of the uniform distribution Figure A-5 clearly illustrates this concept In this example, the two distributions intersect at approximately the 90th percentile, yielding higher soil ingestion rates with a lognormal distribution beyond this point Until the data accommodate a more rigorous evaluation of the shape of the distribution, uncertainty associated with the use of a uniform distribution will remain unresolved

Why Use a Probability Distribution Instead of a Point Estimate? – The use of a probability distribution instead of a point estimate when data are limited is a judgment call that requires consideration of two key factors (1) the objectives of the Monte Carlo modeling approach, and

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(2) the representativeness, quantity, and quality of the available data For this analysis, the ultimate goal is to use quantitative information on variability in exposure to help inform the risk management decisions at Rocky Flats An important component of a Monte Carlo simulation is the sensitivity analysis, which can help to focus the interpretation of the risk distributions on the key variables Variables that are represented by point estimates are essentially excluded from the sensitivity analysis because they do not contribute to variability in the risk estimates Secondly, while the empirical data are sparse, it is reasonable to assume that the two studies were appropriately conducted and that the subjects are representative surrogates for a larger population of adults In other words, the main deficiency is that there are too few measurements to evaluate additional distributions with any confidence The selection of a uniform distribution reflects a balance between the available data, and the information that can be provided for the risk management decision by allowing the adult soil ingestion rate to contribute to the overall sensitivity analysis In addition, the parameters selected for the uniform distribution (min, max), while largely based on judgment, were informed by the available data and do reflect an effort to yield higher soil ingestion rates in the risk model than would otherwise have been obtained with selections of other probability distributions

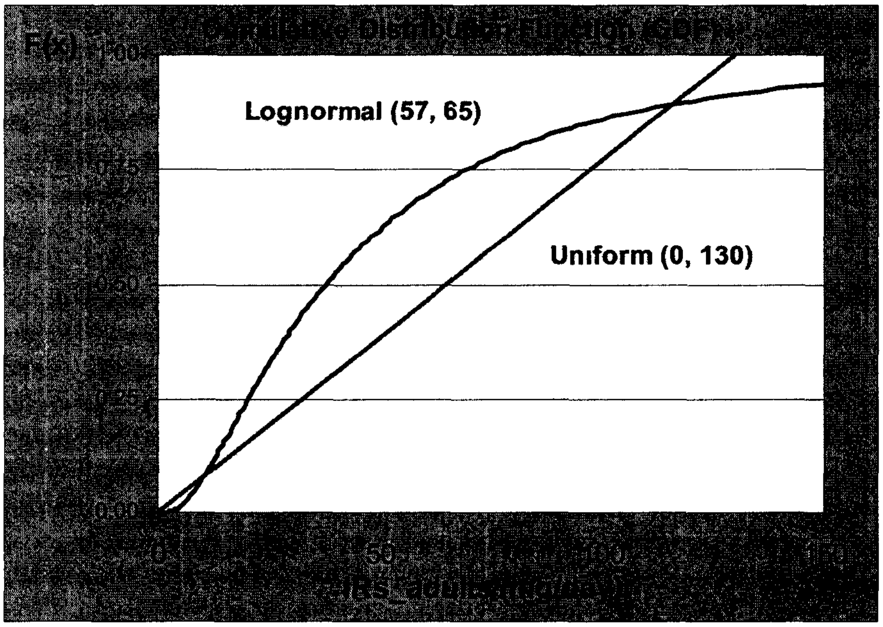

Figure A-5 Comparison of the Uniform (0, 130) and the Lognormal (57, 65) distribution based on the Calabrese et al (1990) results for Al Higher soil ingestion rates are approximately 90% more likely with the use of a uniform distribution (in this example) The uniform is truncated at the maximum value of 130 mg/day, whereas the lognormal is untruncated at the high-end and will yield ingestion rates greater than 130 mg/day approximately 8% of the time

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Table A-7 Confidence ratings for soil ingestion rate for adults (IRs_adult)

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Relevant analyses on data from two study populations are given in the peer review literature	High
• Accessibility	Papers are available from peer review journals One study is evaluated in the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Reproducibility	Methodology is presented in literature but not always at the level of the individual subject-day-trace element level Therefore, the summary results cannot be reproduced from the original data	Medium
• Focus on factor of interest	Studies are designed as pilot studies to validate the mass balance tracer methodology applied to children, adult subjects were fed capsules of soil, and trace element from capsule and food were subtracted from total excreted to yield estimates of incidental soil/dust ingestion	Medium
• Representativeness of study population	Adults ages 22 to 45 years, both male and female, including relevant geographic location (West) Small sample sizes (n = 6, n = 10) and study duration (four weeks or less) plus uncertainty in activities and hobbies during study period	Low
• Primary data	Analyses are based on primary data, with emphasis on two studies (n = 6 and n = 10)	High
• Currency	Studies conducted within the past 15 years	High
• Adequacy of data collection period	Data collected over seven consecutive days in September Difficult to assess if conditions during period reflected a peak period of exposure to soil Not adequate for estimating long-term average behavior because study period was short and did not include multiple time points Insufficient data to generate reliable estimates of day-to-day variability	Medium
• Validity of approach	Fecal tracer mass balance technique is generally considered to be the most reliable technique, despite difficulties in validation Uncertainties include high inter-trace element variability and low precision of recovery for certain subject days, possibly due to absorption of trace elements and variability in GI transit times within subjects and between subjects Best tracer methodology was developed to identify trace element(s) on each subject-day that had the lowest food/soil ratio	Medium
• Study size	See representativeness above	Low
• Characterization of variability	Use of uniform distribution reflects high uncertainty in interindividual variability due to small sample size and inconsistent results by trace elements No attempt was made to quantify intraindividual variability in order to derive a distribution relevant to long-term average	Low

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Considerations	Rationale	Rating
• Lack of bias in study design (high rating is desirable)	Use of soil capsules ensures a higher quantity of trace elements excreted, but numerous days yielded negative mass balance results, especially for the study with n = 10 for which nearly 50% of subject-days had negative estimates	Low
• Measurement error	Potential for inaccurate mass balance calculation due to absorption of trace elements and variability in GI transit times See bias discussion above	Low
Other Elements		
• Number of studies	Two studies using same methodology on populations in different geographic areas	Medium
• Agreement between researchers	General agreement that studies are best available Not much debate yet on selection of probability distributions to characterize variability	Medium
Overall Confidence Rating	Primary data but small sample sizes Repeat measurements over three to four week period, although no attempt to quantify intra-individual variability Uncertainty in mass balance methodology given the number of days of negative ingestion rate estimates	Low

A.1.2 SOIL INGESTION RATE IN CHILDREN (AGES 0 TO 6 YEARS)

A review of the literature on soil ingestion rates was conducted in order to develop a probability distribution function for use in Monte Carlo simulations The probability density function is intended to characterize interindividual variability in long-term average soil ingestion rates among children The following discussion explains the general fecal tracer study methodology used to indirectly assess ingestion rates The most relevant empirical data are summarized, and justification for the most applicable distribution for Rocky Flats is offered

Extrapolation from Short-term to Long-term Average Ingestion Rate – While the goal is to characterize interindividual variability in ingestion rates over long time periods (e g , years), the study designs capture short periods (e g , days) Different approaches can be used to extrapolate from the short-term data to a long-term estimate of variability The simplest approach is to assume that the variability measured over a period of days is representative of the variability over a period of years This is a common assumption in risk assessment, and is presumed to be protective of the exposed population because it will tend to overestimate variability in long-term average ingestion rate The degree to which it may overestimate is unquantifiable without additional empirical data over longer time periods (e g , repeated sampling of the same study population) An alternative approach that has been applied to estimates of soil ingestion rates in children is to use the information available on intraindividual variability over a short time period (e g , 8 days) to extrapolate to estimates of intraindividual variability over a one-year period By repeating this process for the entire study population, an estimate of interindividual variability in one-year average ingestion rates is obtained The results of this statistical approach, along with the relevant studies that describe the statistical analysis of available data, are presented below as the basis for the probability distribution developed for the assessment at Rocky Flats

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A.1.2.1 PROBABILITY DISTRIBUTION

The following probability distribution was developed for use in probabilistic risk calculations

IRs_child ~ Truncated Lognormal (47.5, 112, 0, 1,000) mg/day

The truncated lognormal distribution is defined by four parameters

• arithmetic mean	47 5	mg/day
• standard deviation	112	mg/day
• minimum	0	mg/day
• maximum	1,000	mg/day

For the RESRAD model, the same distribution can be used by converting the units from (mg/day) to (g/yr)

• mean	47 5	mg/day x 0 001 g/mg x 365 day/yr =	17 34 g/yr
• standard dev	112	mg/day x 0 001 g/mg x 365 day/yr =	40 88 g/yr
• minimum	0	mg/day x 0 001 g/mg x 365 day/yr =	0 g/yr
• maximum	1,000	mg/day x 0 001 g/mg x 365 day/yr =	365 g/yr

Therefore, applying the same assumptions as the Standard Risk equations, the equivalent distribution for the child rural resident for use in RESRAD is

IRs_child ~ Truncated Lognormal (17.34, 40.88, 0, 365) g/yr

The basis for the probability distribution is presented in the sections that follow By applying an upper truncation limit to the lognormal distribution, both the central tendency and the variance of the distribution will be reduced when the distribution is used in a Monte Carlo simulation A comparison of summary statistics for the lognormal and truncated lognormal is given in Table A-8 By imposing a relatively high upper truncation limit of one gram per day (1,000 mg/day, which is equivalent to the 99 8th percentile of the lognormal distribution), the "effective" mean and standard deviation (SD) of this distribution are reduced by 6% and 28 6%, respectively (see Figure A-6 below, which shows % change in SD as a function of truncation)

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Table A-8 Comparıson of summary statıstıcs for the lognormal dıstrıbutıon for soıl ıngestıon rate for chıldren when an upper truncatıon lımıt of 1,000 mg/day ıs used

Summary Statıstıc	IRs_chıld (mg/day)	
	Untruncated	Truncated[1]
mean	47 5	44 6
Stand Dev	112 0	79 9
Mınımum	0	0
25th %ıle	7 4	7 4
50th %ıle	18 5	18 5
75th %ıle	46 8	46 5
90th %ıle	107 5	106 1
95th %ıle	177 0	172 9
96th %ıle	204 6	198 9
99th %ıle	450 7	411 4
Maxımum	∞	1,000 0

[1] Mean and standard devıatıon are exact solutıons, percentıles are estımated by Monte Carlo sımulatıon usıng 10,000 ıteratıons and Latın Hypercube samplıng

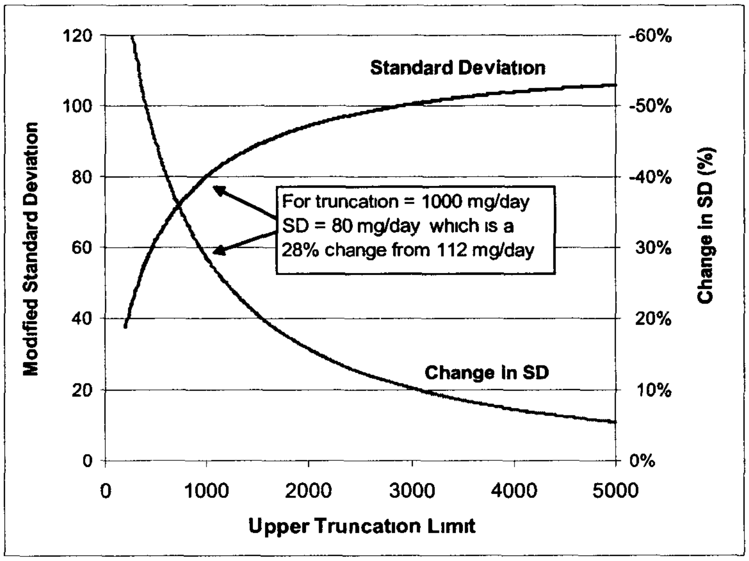

Fıgure A-6 Effect of upper truncatıon lımıt on the standard devıatıon of the lognormal dıstrıbutıon for soıl ıngestıon rate for chıldren

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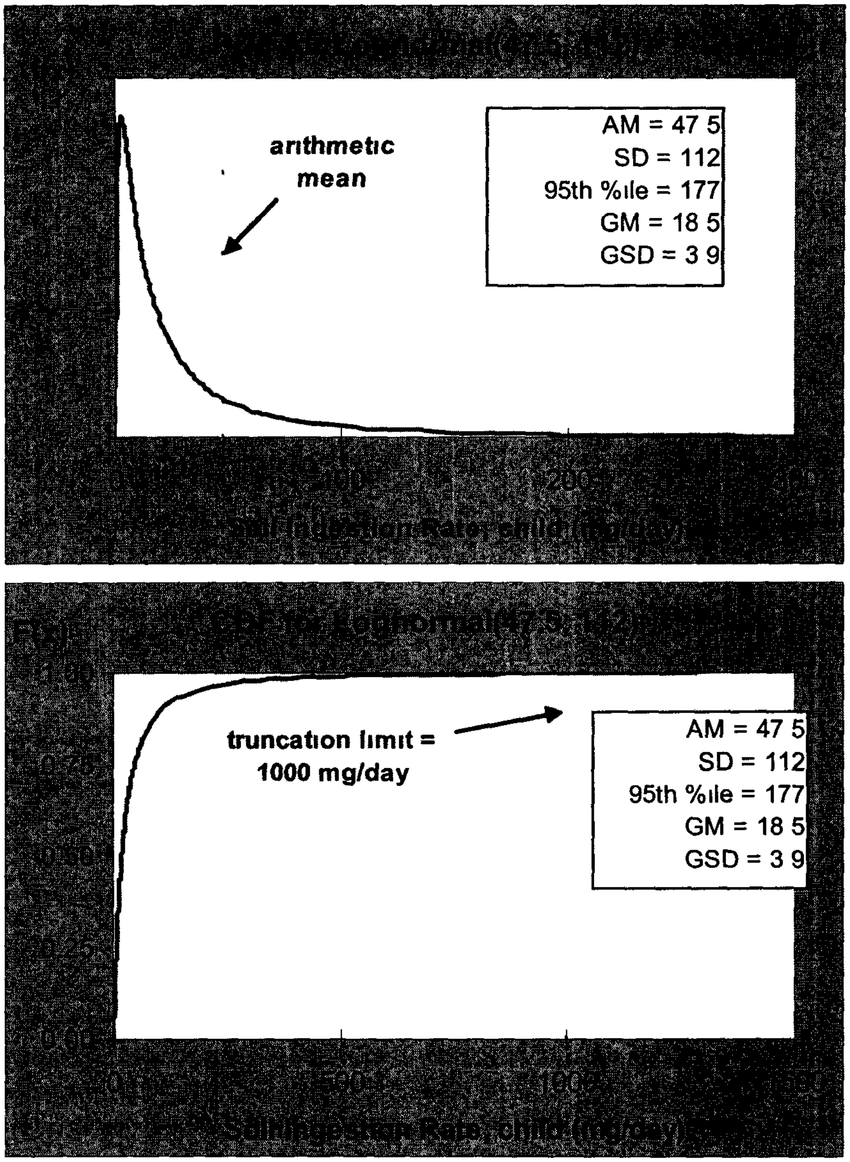

Figure A-7 Probability density function and cumulative distribution function views of the probability distribution for child soil ingestion rate (mg/day) Parameter values given in text boxes correspond to the untruncated lognormal probability distribution

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A.1.2.2 UNCERTAINTIES IN THE PROBABILITY DISTRIBUTION

There are multiple sources of uncertainty associated with the probability density function developed to characterize interindividual variability in childhood soil ingestion rates Stanek et al (2001) gives a comprehensive summary of potential biasing factors

- Determining trace element concentrations in non-soil sources,
- Estimating gastrointestinal transit time from food to fecal samples,
- Implementing exclusion criteria to remove unreliable daily estimates for certain tracer elements,
- Inconsistency among tracer elements in daily estimates,
- Assuming that intra-individual variability is characterized by a lognormal distribution, and that all individuals exhibit the same intra-individual variability, and
- Selecting a maximum value for truncating the probability density function that characterizes inter-individual variability

Selection of a Single Data Set – Multiple studies have been conducted on different study populations, including Anaconda, Amherst, and Washington State As discussed above, the Anaconda study is considered to be more representative of the variability in soil ingestion rates among children that may be exposed in a residential scenario at Rocky Flats It may be tempting to combine the data sets in order to increase the sample size and capture the "heterogeneity" among subpopulations of children in different locations Given the number of differences in study design, data analysis, and population characteristics, it is not appropriate to combine the data for purposes of characterizing variability in soil ingestion rates The different data sets do provide a measure of uncertainty, and it might be of interest to develop separate probability density functions for each data set This level of quantitative uncertainty analysis is beyond the scope of this appendix

Uncertainty Due to Model Time Step – A model time step is essentially an averaging time—it refers to the time period represented by a random value selected from a probability distribution For most Monte Carlo models, a single random value is selected to represent a long-term average value For example, for a single iteration of the model (representing a hypothetical child), a random value may be selected from the empirical distribution function in order to represent the average daily ingestion rate over seven years This is a simplifying assumption given the lack of longitudinal data on ingestion rates among individuals An alternative would be to represent the seven-year average value by selecting seven random year values, essentially simulating an individual's exposures over time In general, distributions based on estimates of short-term surveys will tend to overestimate the variability in long-term average values Until repeat measures are used to estimate ingestion rates among a population, intraindividual variability will remain an unquantifiable source of uncertainty

The importance of the model time step assumption can be explored Explicit model time steps can be employed to simulate an individual's exposures over time For example, Stanek (1996) applies an annual time step because he assumes that the empirical distribution described above represents interindividual variability over a one-year period (i e , a single random sample from this distribution represents the average IR_{soil} for an individual for the year) According to the

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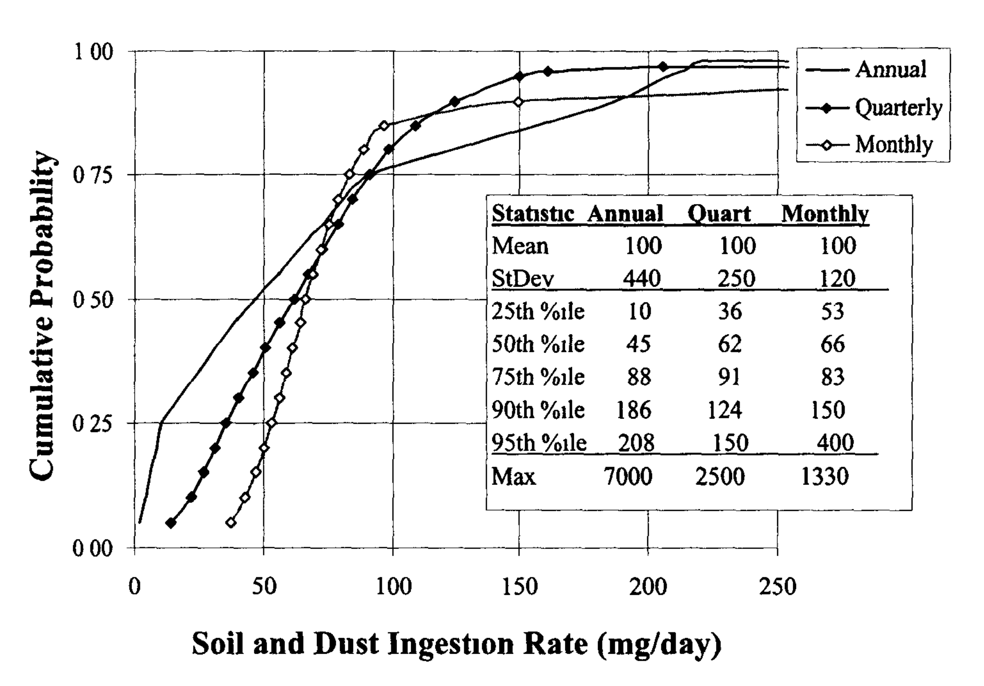
central limit theorem, the SD of the sample distribution is inversely proportional to the square root of *n* Thus, decreasing the time step from one year to one month would increase the number of random samples needed to estimate the average annual ingestion rate, and effectively reduce the SD of the distribution by a factor of approximately 3 5 (Goodrum et al , 1996) The effect that changing the model time step has on the distribution of IR_{soil} is summarized in Figure A-8

Several alternative approaches to simulating intraindividual variability could be explored, but were not in this analysis For example, the method suggested by Stanek (1996) could be used to derive the response error variance of the best subject-day estimates of IR_{soil} given by the Daily Estimate Method The resulting empirical distribution could be considered a measure of both the latent distribution and short-term variability in IR_{soil} The model time step could then be used to explore the effect of uncertainty in extrapolating distributions over different time intervals Another approach would be to auto correlate random samples by constraining the sample space to a percentile range of the cumulative probability density function For example, if an individual was assumed to have a high latent exposure (e g , more than 88 mg/day, the upper quartile of the IR_{soil} probability density function), each consecutive random value could be weighted to the upper quartile (i e , greater than 75th percentile) of the distribution This approach would simulate both the underlying, latent distribution (i e , relatively high IR_{soil}), as well as the stochastic, short-term variability in average ingestion rates for each consecutive time step (i e , between 88 and 7,000 mg/day)



Statistic	Annual	Quart	Monthly
Mean	100	100	100
StDev	440	250	120
25th %ile	10	36	53
50th %ile	45	62	66
75th %ile	88	91	83
90th %ile	186	124	150
95th %ile	208	150	400
Max	7000	2500	1330

Figure A-8 Cumulative distributions of soil and dust ingestion rates based on different model time steps using Monte Carlo simulations of n = 5,000 iterations and the Amherst cohort (Calabrese et al , 1989)

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The methodology and data analysis associated with the published estimates of child soil ingestion rates is complex An overview of the methodology is given below in order to highlight the major assumptions and uncertainties associated with the development of the distribution

A.1.2 2 1 FECAL TRACER METHODOLOGY FOR ESTIMATING SOIL INGESTION RATE

Empirical estimates of soil ingestion rates (IR_{soil}) in children have been made by backcalculating the mass of soil and/or dust a subject would need to ingest to achieve a tracer element mass measured in collected excreta (i e , feces and urine) (Calabrese et al , 1996) Equation 1 gives the general expression for the trace element ("tracer") mass balance

$$[tracer]_{out} - [tracer]_{in\ nonsoil} = [tracer]_{in\ soil}$$

where $[tracer]_{out}$ is the average daily tracer mass (µg) measured in feces and urine, $[tracer]_{in,\ non\text{-}soil}$ is the average daily tracer mass measured in non-soil ingesta (i e , food, water, toothpaste, and medicines), and $[tracer]_{in,\ soil}$ is the estimated average daily tracer mass in ingested soil Dividing all terms by the measured tracer concentration in soil (µg/g) yields an estimate of the average daily soil ingestion rate, as given by Equation 2

$$\frac{[tracer]_{out} - [tracer]_{in\ nonsoil}}{\frac{[tracer]_{soil}}{[soil]}} = \frac{[tracer]_{in\ soil}}{\frac{[tracer]_{soil}}{[soil]}} = [soil] = IR_{soil}$$

A 1.2 2.2 EMPIRICAL DATA

Three seminal studies, briefly summarized below, used this mass-balance approach and were considered appropriate for quantifying variability and uncertainty in IR_{soil} Pathways for non-soil/non-food intake of tracers (e g , inhalation and dermal absorption) and excretion (e g , sweat and hair) were not measured in these studies and are thought to be minor components of the overall tracer mass balance (Barnes, 1990)

Calabrese et al. (1989) – Eight trace elements (Al, Ba, Mn, Si, Ti, V, Y, and Zr) were measured in a mass-balance study of 64 children ages one to four years over eight days (i e , four days per week for two weeks) during late September and early October Participants represent a nonrandom study population selected from day-care centers and volunteer families in an academic community in Amherst, MA A single composite soil sample was collected from up to three outdoor play areas identified by parents as locations where subjects spent the most time Similarly, indoor dust samples were vacuumed from floor surfaces that parents reported to be common play areas during the study Each week, duplicate food samples were collected for three consecutive days, and fecal samples (excluding diaper wipes and toilet paper) were collected for four consecutive days for each subject A total of 128 subject-week estimates of IR_{soil} were made Also, since food and fecal samples were collected on multiple days per subject, a total of 439 subject-day estimates of IR_{soil} were also made (Stanek and Calabrese, 1995a) For each subject-week-day, a maximum of eight estimates of IR_{soil} were made, each estimate corresponding to a unique trace element

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Davis et al. (1990) – Three trace elements (Al, Si, and Ti) were measured in a mass-balance study of 101 children ages 2 to 7 years over four consecutive days during the summer Participants represent a random sample of the population in a three-city area of southeastern Washington State A single composite soil sample was collected from outdoor play areas identified by parents Indoor dust samples were collected by vacuuming floor surfaces of the child's bedroom, the living room, and the kitchen, as well as by sampling the household vacuum cleaner Information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil ingestion Although duplicate food and fecal samples (including diaper wipes and toilet paper) were collected on a daily basis, samples for each individual were pooled to derive a one-week average estimate of IR_{soil} A total of 101 subject-week estimates of IR_{soil} were made For each subject-week, a maximum of three estimates of IR_{soil} were made, each estimate corresponding to a unique trace element

Calabrese et al. (1997a) – Eight trace elements (Al, Si, Ti, Ce, Nd, La, Y, and Zr) were measured in a mass-balance study of 64 children ages 1 to 3 years over seven consecutive days during September Participants were selected from a stratified simple random sample of approximately 200 households from six geographic areas in and around Anaconda, MT A single composite soil sample was collected from up to three outdoor play areas identified by parents as locations where subjects spent the most time Similarly, indoor dust samples were vacuumed from floor surfaces that parents reported to be common play areas during the study Duplicate food and fecal tracer element samples were collected for 448 and 339 subject-days, respectively A total of 64 subject-week estimates of IR_{soil} were made, subject-day estimates of IR_{soil} have recently been published (Stanek and Calabrese, 1999, 2000, Stanek et al , 2001a) Three trace elements (Ce, La, and Nd) were not used to estimate IR_{soil} because soil concentrations of these elements were found to vary by particle size (Calabrese et al , 1996) For each subject-week, a maximum of five estimates of IR_{soil} were made, each estimate corresponding to a unique trace element Final soil ingestion estimates are based on soil particle size less than 250 μm (as opposed to 2,000 μm)

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Table A-9. Confidence ratings for soil ingestion rate for children (IRs_child) for Rural Resident scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Relevant analyses on data from two study populations are given in the peer review literature	High
• Accessibility	Papers are available from peer review journals and are evaluated in *Exposure Factors Handbook* (U S EPA, 1997)	High
• Reproducibility	Methodology is presented in literature but without original survey data so results cannot be reproduced	Medium
• Focus on factor of interest	Studies are designed to quantify incidental ingestion of soil by children, including soil transported indoors (dust)	High
• Representativeness of study population	Key study represents children of relevant ages (1 to 3 years), both male and female, including relevant geographic location (West) Difficult to assess representativeness of race and socio-economics, and potential bias (underestimation) introduced by selection of population near a smelter site who may have altered exposure patterns in response to educational outreach	Medium
• Primary data	Analyses are based on primary data	High
• Currency	Studies conducted within the past 10 years	High
• Adequacy of data collection period	Data collected over seven consecutive days in September Difficult to assess if conditions during period reflected a peak period of exposure to soil Not adequate for estimating long-term average behavior because study period was short and did not include multiple time points Insufficient data to generate reliable estimates of day-to-day variability	Medium
• Validity of approach	Fecal tracer mass balance technique is generally considered to be the most reliable technique, despite difficulties in validation Uncertainties include high inter-trace element variability and low precision of recovery for certain subject days, possibly due to absorption of trace elements and variability in GI transit times between subjects and within subjects	Medium
• Study size	Both the number of subjects and duration of study period affect the quantity of subject-days of data Sixty-four children were studied in two key studies, ranging from 5 to 8 days	Medium
• Characterization of variability	High uncertainty in use of lognormal distribution to characterize intra-individual variability in order to extrapolate to long-term average ingestion rates Method does not account for potential correlation between mean and SD on an individual child basis (all children are assumed to exhibit the same short-term variability Lognormal distribution fit to reported percentiles is adequate, but uncertainty in upper truncation limit (1,000 mg/day)	Low

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Considerations	Rationale	Rating
• Lack of bias in study design (high rating is desirable)	Key study population is from relevant geographic location, but potential bias from selection of population near a smelter site Soil was sieved to yield a more representative size fraction of soil for exposure Exclusion criteria remove daily estimates for selected trace elements thought to be unreliable, but cutoff is subjective	Medium
• Measurement error	Potential for inaccurate mass balance calculation due to absorption of trace elements and variability in GI transit times	Medium
Other Elements		
• Number of studies	Two key studies using same methodology on populations in different geographic areas	Medium
• Agreement between researchers	General agreement that studies are the best available Not much discussion yet on selection of probability distributions to characterize variability	Medium
Overall Confidence Rating	Variability over one week period may overestimate variability extrapolated to one year Uncertainty in mass balance methodology, and assumption associated with selection of probability distribution type and parameters Recent, primary data from representative population, and moderate sample size	Medium

A 1.2.3 INTERPRETATION OF INTER-TRACER VARIABILITY IN SOIL INGESTION

Trace elements were selected for estimating soil ingestion in these mass-balance studies because they are natural constituents of soil, present in relatively low concentrations in food, poorly absorbed in the GI tract, and not inhaled in appreciable amounts (Barnes, 1990) Theoretically, each trace element should yield the same estimate of daily soil ingestion using Equation 2 However, the following sources of measurement error are attributed to the high inter-tracer variability and low precision of recovery observed for many subject-days in each study

- High element concentration in food, yielding a high food-to-soil (F/S) ratio (Calabrese and Stanek, 1991),
- Variability in food transit times between subjects and between subject-days for a given child resulting in input/output misalignment errors, and lower precision of recovery for elements with higher F/S ratios (Stanek and Calabrese, 1995b), and
- Incomplete collection of both inputs (e g , additional non-soil sources of tracer) and outputs (e g , fecal samples on diaper wipes and toilet paper, urine samples for elements with low fecal-to-urine ratios)

The adult validation study by Calabrese et al (1989, 1990) demonstrated that negative soil ingestion estimates occur more frequently for trace elements with high F/S ratios At a low dose of soil (100 mg/day), 7 of 48 (15%) subject-days displayed negative IR, while at a high soil dose (500 mg/day), no subjects displayed negative IR The adult study by Calabrese et al (1997a), which used a slightly different set of trace elements, demonstrated a sufficiently high recovery for most elements to quantify ingestion rates in the range 20 to 500 mg/day These results may also apply to children, keeping in mind potential differences in the following areas among

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different age groups. GI transit times, absorption efficiencies, F/S ratio, and variability in daily tracer ingestion (Calabrese and Stanek, 1991). For the studies with children, negative IR estimates were observed on 12 to 44% of subject-days (depending on the trace element) by Calabrese et al. (1989), 12 to 32% by Davis et al. (1990), and approximately 55% (preliminary assessment of Al and Si) by Calabrese et al. (1997a). Given that high inter-tracer variability in subject-day estimates of IR_{soil} is a function of both tracer-specific properties and input/output errors, it is unlikely that a reliable estimate of IR_{soil} for all subject-days can be derived from any single trace element. This is confirmed by the differences in estimates of ingestion rates among different tracers. For example, tracer-specific estimates of median IR_{soil} in the Calabrese et al. (1989) study range by an order of magnitude (i.e., 9 to 96 mg/day). The following two methodologies have been developed to identify the set of trace elements that is likely to provide the most reliable estimate of IR_{soil}.

Best Tracer Method (BTM) – Each subject-week estimate of IR_{soil} is based on the trace element(s) with the best (i.e., lowest) F/S ratios for that week (Stanek and Calabrese, 1995b). This approach reduces the effect of transit time errors (i.e., poor temporal correspondence between food and fecal samples). Potential bias from other sources of error for specific tracers may be reduced by estimating the median of multiple tracers with low F/S ratios for a subject-week. Stanek and Calabrese (1995a) recommend estimating the distribution of IR_{soil} based on the median of the four best tracers for each subject-week. Using this approach, data from the Calabrese et al. (1989) and Davis et al. (1990) studies were combined to yield 229 subject-week estimates of IR_{soil} representing 165 children between the ages of 0 and 6.

Daily Estimate Method – A single estimate of IR_{soil} is made for each tracer-subject-day for each child (Stanek and Calabrese, 1995a, 2000). A maximum of eight such estimates (one per tracer) was determined for each of 64 children in the Calabrese et al. (1989) study. This approach establishes a set of criteria to identify tracer-subject-day estimates that may be unreliable for each subject-week, based on the relative standard deviation (RSD) given by Equation 3.

$$\Delta_i = max(50, d_i e^{[1.5-0.35\, ln(d_i)]})$$

$$\delta_i = \left| d_{ij} - d_i \right|$$

$$RSD_i = \frac{\Delta_i}{\delta_i}$$

where d_i is the median IR_{soil} for the i^{th} day of a given subject-week, d_{ij} is the IR_{soil} for the j^{th} tracer on the i^{th} day of a given subject-week, Δ_i is the maximum of either 50 mg/day or a function of d_i, and δ_i is the absolute value of the difference between a single tracer element and the median among the group of tracers on a given day. Stanek and Calabrese (1995a) limited the maximum value of Δ_i to 50 mg/day to reduce any bias associated with low median estimates of IR_{soil}. If, for a given d_i, δ_i more than Δ_i, then RSD less than 1.0 and element j is identified as an outlier estimate of IR_{soil}. The median of the remaining tracers for each subject-day was considered the best estimate of IR_{soil}.

The Daily Estimate Method attempts to correct for positive and negative mass-balance errors at the level of the subject-day. This approach reduces the effect of transit time errors by directly

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linking the passage of food and fecal samples for each daily estimate Like the BTM approach, it reduces tracer-specific source errors by calculating the median of multiple tracer estimates An advantage of this approach over BTM is that it also allows for an estimate of intraindividual (within subject) variability in IR_{soil} After applying the RSD exclusion criteria to the Calabrese et al (1989) Amherst data, daily estimates of IR_{soil} (based on the median of tracer-specific estimates) were available for at least four days for all subjects, and at least six days for 94% of the subjects (Stanek and Calabrese, 1995a) Assuming each subject's daily IR_{soil} is lognormally distributed, subject-specific parameters for lognormal probability density functions were defined based on the mean and variance of the 4 to 8 daily IR_{soil} values Each lognormal probability density function was then used to define daily ingestion rates over a 365-day period The use of a lognormal distribution (instead of other right-skewed distribution) is an acknowledged source of uncertainty that was not explored further due to the limited number of days of data for each individual (Stanek and Calabrese, 1995a) A similar approach could not be applied to the Davis et al (1990) data because daily estimates of IR_{soil} were combined to define subject-weeks This approach was also applied to the Calabrese et al (1997a) Anaconda data (Stanek and Calabrese, 2000) as summarized in Table A-10 in Section 1 2 5

A.1 2 4 EVALUATION OF SHORT-TERM AND LONG-TERM EMPIRICAL DISTRIBUTION FUNCTION'S (EDF) FOR SOIL INGESTION RATE

As of 1994, estimates of childhood soil ingestion rates from short-term studies were assumed to be representative of long-term rates U S EPA (1994 a, b) recommended a default central tendency estimate (CTE) of IR_{soil} = 135 mg/day for ages 12 months to less than 48 months based on a review of mean tracer-specific estimates given by Binder, et al (1986), Clausing, et al (1987), Calabrese et al (1989), and Davis et al (1990) Currently, only two of the mass balance fecal tracer studies are suitable to estimate daily soil ingestion rates needed to develop estimates of long-term average rates (1) Amherst, MA (Calabrese et al , 1989, Stanek and Calabrese, 1995a) and (2) Anaconda, MA (Calabrese et al , 1997a, Stanek and Calabrese, 2000, Stanek et al , 2001a) Table A-10 summarizes the estimates of interindividual variability in IR_{soil} derived from the results of the three soil ingestion studies with children that used a mass-balance approach An empirical cumulative distribution function (ECDF) was developed from the summary statistics derived by the Daily Estimate Method (i e , Daily Mean, 1+) applied to both the Amherst and Anaconda data These studies and the statistical approach were selected for the following reasons

- The ingestion rates estimated by Calabrese et al (1989) generally have less uncertainty related to input/output misalignment error than the estimates by Davis et al (1990) For example, nearly 90% of the subject-weeks reported by Calabrese et al (1989) had at least two trace elements with F/S ratios lower than the lowest F/S ratios reported in the Davis et al (1990) study (Stanek and Calabrese, 1995b) In addition, although titanium (Ti) has relatively low F/S ratios in both studies, it displayed exceptionally high source error (Calabrese and Stanek, 1995, Stanek et al , 2001) Consequently, Ti, one of only three tracers used in Davis et al (1990), may provide unreliable estimates of IR_{soil}

- The Daily Estimate Method is preferred over BTM because (1) it identifies sources of potential measurement error at the level of the subject-day rather than the subject-week,

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and (2) intraindividual variability in IR_{soil} can be quantified and extrapolated over longer time periods Both of the studies by Calabrese (1989, 1997a) data are amenable to this method, whereas the Davis et al (1990) estimate of IR_{soil} is for subject-weeks

Three key assumptions were made in developing a probability distribution from each of the Calabrese data sets using the Daily Estimate Method

(1) Subject-day estimates of IR_{soil} are reasonable approximations of the combined ingestion of outdoor soil and indoor dust For simplicity, Stanek and Calabrese (1995a) based all soil ingestion estimates on trace element concentrations in soil, not dust Theoretically, if concentrations in soil and dust were the same, this approach would correctly account for ingestion from both sources Relative differences in average concentrations between outdoor soil and indoor dust for the Calabrese et al (1989) study range from 6 to 55% for different trace elements (Stanek and Calabrese, 1992) Calabrese et al (1989) proposed apportioning residual fecal tracers using a time-weighting approach, which assumes that soil ingestion is proportional to time spent in a particular location This is also a simplistic approach since soil and dust exposure may vary due to differences in hand-to-mouth activity, weather, and degree of adult supervision For the data used to generate a probability density function for Rocky Flats, no attempt was made to account for potential differences between soil and dust ingestion rates

(2) A reasonable upper bound for variability in the long-term average ingestion rate is 1,000 mg/day This assumption reflects an understanding of both intraindividual and interindividual ingestion rates There is considerable intraindividual variability over a one-year period with respect to the frequency and magnitude of soil ingestion While most children ingest relatively small amounts of soil on most days, occasionally they will ingest large quantities (i e , more than 1,000 mg/day) Therefore, while the annual average IR_{soil} may be low for a given child, day-to-day variability may result in several subject-days of high IR_{soil} per year This hypothesis is suggested by U S EPA (1994a) and supported by soil ingestion studies by Calabrese et al (1989) and Wong (1988), as summarized by Calabrese and Stanek (1993) In the Calabrese et al (1989) study, one child ingested an estimated 20 to 25 grams of soil on 2 of 8 days (Calabrese, et al , 1993) A second child displayed more consistent but less striking soil pica in which high soil ingestion (1 to 3 g/day) was observed on 4 of 7 days (Calabrese et al , 1997b) Wong observed soil pica (i e , more than 1 0 g/day) in 9 of 84 individual subject-days (10 5%) for Jamaican children ages 0 3 to 7 5 years, and at least 1 of 4 days for 5 of 24 (20 8%) children of normal mental capability One mentally retarded child displayed consistently extreme soil pica over the four days (48 3, 60 7, 51 4, and 3 8 g soil)

Stanek and Calabrese (1995a) fit individual subject-day estimates from Calabrese et al (1989) to lognormal distributions to estimate the number of days per year each child might be expected to ingest more than 1 0 g/day Model-based predictions suggest the majority (62%) of children will ingest more than 1 0 g soil on 1 or 2 days/yr, while 42% and 33% of children were estimated to ingest more than 5 and more than 10 g of soil on 1 or 2 days/yr, respectively

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(3) The developmental period during which the frequency and magnitude of soil ingestion is likely to be the greatest coincides with the period of peak hand-to-mouth activity (i e , ages 1 to 4 years) It should be noted that empirical data from the mass-balance studies do not provide any evidence that children ages 1 to 4 years ingest more soil than other age groups (Calabrese and Stanek, 1994)

For simplicity, it is assumed that random values selected from this distribution are independent for each time step of exposure In other words, the latent distribution of individual ingestion rates is assumed to be equal for all individuals in the population It is more plausible that patterns of soil ingestion rate for an individual are a combination of a latent distribution and some measure of day-to-day variability Several approaches may be used to simulate this type of exposure pattern in a population Stanek (1996) combined a latent distribution and response error distribution (for tracers Al, Si, Y) to define an empirical distribution, and then extrapolated the empirical distribution over 365 days The same approach was employed for the Anaconda data (Stanek and Calabrese, 2000), resulting in 75% lower values for the 365-day average than for the daily values The resulting distributions are given in Table A-10 The response error variance was calculated as the variance in subject-day estimates of $\ln(IR_{soil})$ divided by the number of subject-day estimates for a given child The average response error variance among all 64 Amherst subjects was 0 47, while the average number of subject-days per child was 6 1 Converting to an anti-logarithm estimate, the average standard deviation (SD) in daily soil ingestion was approximately 66 mg/day

A similar approach was used to determine variance estimates for the Anaconda data (see Table IV of Stanek and Calabrese, 2000) For purposes of comparison, day-to-day variance in soil ingestion from the Anaconda study (excluding titanium and Tukey far-out) was reported as 9,094 (SD = 95 mg/day), whereas day-to-day variance from the Amherst study (including aluminum, silicon, yttrium, zirconium) was 15,528 (SD = 124 mg/day) These expressions provide the only quantitative measure of intraindividual variability in IR_{soil}

Extrapolating the empirical distribution over 365 days assumes that the response error variance measured over a short-term period (i e , subject-week) is the same as the variance over a long-term period (i e , 365 days) In addition, it assumes that the variance is independent of the average daily IR_{soil} for a given subject week The upper tail of the empirical distribution may be underestimated if a positive correlation exists between the mean and variance of IR_{soil} for a given subject-week This source of uncertainty could be explored for both Amherst and Anaconda subject-day estimates, but was not for this analysis

A.1.2.5 FINAL SELECTION OF PROBABILITY DISTRIBUTION FOR SOIL INGESTION RATE

The Anaconda data (Calabrese et al , 1997a) are generally considered to be more representative of the potentially exposed population of children at the Rocky Flats

- Study population is from the West (Montana),
- Soil was sieved at 250 µm, a more representative size fraction for particle adherence to hands, and also the size fraction with the least uncertainty in trace element concentrations,

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- Exclusion criteria for daily tracer estimates resulted in a much larger database of subject-day estimates from which to develop statistical summaries. Exclusion criteria applied to the Anaconda data eliminated estimates based on Ti, and Tukey outlier criteria excluded 18 of 2,984 element-subject days (i.e., 0.45%) compared with 31.9% that would have been eliminated if the Amherst outlier criteria had been applied (Stanek and Calabrese, 2000). Outlier criteria applied to the Amherst study resulted in exclusion of 37.5% of the data (Stanek and Calabrese, 2000).

It is unclear what factors are responsible for study-to-study differences in soil ingestion rates, as was observed between the Amherst and Anaconda cohorts. The empirical distribution function is a convenient distribution for characterizing the data sets given a relatively high portion of negative values reported for ingestion rate. Non-negative continuous distributions fit to the empirical distribution function, such as lognormal, gamma, and Weibull, generally yield poor fits, as discussed by Schulz (2001). Alternatively, a series of mixed distributions or conditional distributions could be developed to make use of parametric distributions such as the lognormal for all non-negative values, these approaches are not presented in the literature.

While the percentile data can be entered into a Monte Carlo analysis as an empirical distribution function, a decision would still be needed regarding the minimum and maximum values of the distribution. Since negative values cannot be employed in a risk assessment, a lower truncation limit of 0 mg/day must be used, and could be assumed to define the minimum. This truncation limit is extended to all of the percentile values corresponding to non-negative ingestion rates. For the Anaconda data, negative values were obtained for the 25th percentile (IR_{soil} = -3 mg/day), which carries through to the best linear unbiased predictor estimates as high as the 7th percentile (see Table A-10) (Stanek et al., 2001, Table 3). The empirical distribution function developed by Stanek et al. (2001) for the long-term average ingestion rates was employed in this analysis (last column in Table A-10), and can be approximated by a lognormal distribution. For purposes of maximum likelihood estimates of the mean and SD of the lognormal distribution, a maximum of 150 mg/day was applied (slightly greater than the 99th percentile value of 137 mg/day). The choice of the maximum value for truncation can be an important source of uncertainty in risk estimates if there is a high positive correlation between risk and IR_{soil}, especially at the upper tail of the risk distribution (e.g., greater than 90th percentiles). The goodness-of-fit techniques are also sensitive to the choice of maximum values on the empirical distribution function.

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Table A-10 Distribution of soil ingestion rates (mg/day) based on different methods of analyzing trace element-specific data from mass-balance studies

Summary Statistic	Amherst, MA (n = 64) Calabrese et al , 1989, Stanek and Calabrese, 1995a					Davis et al , 1990	Anaconda, MT (n = 64) Calabrese et al , 1997a, Stanek and Calabrese, 2000, Stanek et al , 2001a			
	Median Al, Si, Ti	**Median[a] Top 4**	**Daily[b] Mean, 1+**	**Latent[c] Al, Si, Y**	**Empirical[d] Al, Si, Y**	**Median Al, Si, Ti**	**Median[e] Top 4**	**Daily[b] Mean, 1+**	**365-day average[h]**	**BLUP[i]**
N	128[f]	128[f]	440[g]	391[g]	391[g]	101[f]	64[f]	427[g]	427[g]	64[f]
Min	< 0	< 0	< 0	0	0	< 0	< 0	< 0	< 0	< 0
Max	11,874	11,415	7,703	470	745	905	380	219	165	137
Mean	147	132	179	20	26	69	7	31	23	na
SD	1,048	1,006	na	26	47	146	75	56	na	na
Percentile										
5th	< 0	< 0	na	2	2	< 0	< 0	< 0	< 0	< 0
10th	< 0	< 0	na	4	3	< 0	< 0	< 0	< 0	2
25th	6	9	10	7	6	15	< 0	< 0	< 0	12
50th	30	33	45	12	13	44	< 0	17	13	25
75th	72	72	88	24	28	116	27	53	40	42
90th	188	110	186	43	56	210	73	111	83	75
95th	253	154	208	60	89	246	160	141	106	91

[a] Best Tracer Method, median of best 4 of 8 tracers (i e , 4 lowest F/S ratios) for a given subject-week (Table 6, Stanek and Calabrese, 1995b)
[b] Daily Estimate Method, mean of subject-day estimates for 1 to 8 days, where each day includes at least one (1+) trace element (Table 6, Stanek and Calabrese, 1995b, Table 2, Stanek and Calabrese, 2000)
[c] Latent distribution for tracers (Al, Si, and Y), mean (2 5) and variance (0 89) of subject-day log (soil ingestion) fit to a lognormal distribution and randomly sampled 2,000 times (Stanek, 1996, p 883)
[d] Empirical distribution for tracers (Al, Si, and Y), combines between-subject variance (latent variance divided by the number of subject-day estimates for each child (Stanek, 1996) Empirical distribution estimated as the sum of 2,000 random samples from the latent and response error distribution, see footnote c) and within-subject variance (response error distribution—parameters fit to lognormal probability density function {mean = 0, variance = 0 47}) Response error variance calculated as the mean of the within-subject standard error distributions
[e] Best Tracer Method, median of best 4 of 5 tracers (i e , lowest F/S ratios) for a given subject-week (Table 13, Calabrese et al , 1997a)
[f] Number of subject-weeks represented by summary statistics
[g] Number of subject-days represented by summary statistics
[h] Extrapolation to 365-day average versus variance components for subjects, days, and error—represented by a "shrinkage constant", yields 25% lower values (e g , 95th percentile reduces from 141 mg/day to 106 mg/day) (Stanek and Calabrese, 2000, p 632, last paragraph)
[i] Stanek et al (2001a, Table 3) and reanalysis of Stanek and Calabrese (1999) results by T Schulz (2001) (Table 1) based on best linear unbiased predictors and small sample variance for subject-days

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A lognormal distribution with an AM of 47 5 mg/day and SD of 112 mg/day was fit to the percentile data using @Risk's Best Fit software (version 3 1) A tabular and graphical summary of the distribution is presented in Figure A-7 The reasonable maximum exposure (RME) point estimate recommended for children (U S EPA, 1991a) of 200 mg/day is approximately the 96th percentile of this distribution The lognormal distribution is bounded at 0 by definition, but has an infinite right tail Given the importance of the soil ingestion rate variable in risk assessment, it is prudent to impose an upper truncation limit so that each iteration of the Monte Carlo simulation yields plausible results The choice of an upper truncation limit is a professional judgment that weighs the confidence in the empirical data, the skewness of the probability distribution fit to the data, and a rule of thumb to avoid overly truncating the distribution (i e , select values that remove less than 1% of the distribution) For this analysis, an upper truncation limit of 1,000 mg/day was chosen This value is the 99 8th percentile of the distribution, and therefore constrains only 0 2% of the values

A.1.3 PLANT INGESTION RATE – VEGETABLE, FRUIT, AND GRAIN

For the Rural Resident land use scenario, one potential exposure pathway is the consumption of plants grown in a family garden Homegrown commodities considered in this analysis include vegetables, fruit, and grain The total amount of these foods ingested on an average day may be thought of as the sum of the homegrown foods plus the foods purchased from the market The ideal data set for estimating *interindividual* variability (between individuals) in average daily ingestion rates among children and adults would include information on factors described below (see Table A-12) These factors may provide a benchmark for determining the representativeness of ingestion rate data for purposes of a risk assessment for the Rural Resident exposure scenario

The USDA Nationwide Food Consumption Survey (NFCS) is the largest publicly available source of information on food consumption habits in the United States Data from the most recent survey conducted in 1987–1988, which included approximately 4,300 households and 10,000 individuals, have been summarized in *Exposure Factors Handbook* (U S EPA, 1997) Respondents estimated intakes over a one-week period These data summaries were used to develop probability distributions to characterize variability in average daily ingestion rates of vegetables and fruits, as described in detail below

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Table A-11 Examples of information on vegetable, fruit, and grain ingestion rates that would provide high confidence in the risk estimates for the residential scenario

Item	Information	Importance for Risk Assessment
1	Fraction homegrown	Risk assessments generally focus on exposures resulting from on site contamination Foods grown on site are more relevant than foods purchased from the market If fraction homegrown is not considered, risks will generally be overestimated for most populations
2	Consumers only	The target population for the risk assessment is individuals who consume vegetables, fruit, and/or grain Individuals that do not consume these commodities in general (or during the short study period of the survey) would be included in "per capita" estimates, which would be lower than "consumer only" estimates Estimates for consumers only would be more representative
3	Season-specific estimates	Dietary patterns may shift seasonally depending on the availability of certain commodities, especially when the risk assessment focuses on homegrown (rather than store-bought) items Long-term estimates of average daily ingestion rates would be biased if they did not account for seasonal variability Seasonal ingestion rates are likely to vary by region (see Item 5), depending on the climate, length of the growing season, and availability of alternative foods from the same category (e g , fruit and vegetables)
4	Short-term and long-term average daily rates	National Survey Data typically reflect dietary patterns over a short period of time (e g , one-week), whereas a risk assessment generally focuses on long-term exposures, especially for chronic health endpoints like cancer In the absence of data providing estimates from a subpopulation over multiple time intervals, reasonable assumptions are needed to extrapolate to longer time periods
5	Region-specific estimates	Estimates based on a subset of the data representative of a region or county can indirectly account for both environmental factors (e g , climate and soil type) and demographic factors (e g , race, ethnicity, economic status, and degree of urbanization) Data grouped into the West are most relevant to sites in Colorado
6	Age-specific estimates	For the Rocky Flats assessment, residents are assumed to begin exposures during childhood (less than seven years) and continue through adulthood (more than seven years)
7	Relevant subgroups of commodities	Some plants, such as leafy vegetables, may be a source of exposure either due to uptake of radionuclides from soil or deposition of contaminated dusts on the leafy surfaces By contrast, foliar deposition is not expected to contribute to exposures for non-leafy vegetables (e g , carrots) Ingestion rates that distinguish leafy from non-leafy vegetable consumption are preferred in the risk assessment

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The USDA Continuing Survey of Food Intakes by Individuals (CSFII), together with NFCS, is the primary source of information on ingestion rates of grain products in the United States Data from the 1989–1991 CSFII survey, which is considered to be the key study for intake rates of grain products (U S EPA, 1997), were used to develop probability distributions to characterize variability in average daily ingestion rates of total grain, as described below Respondents estimated intakes over a three-day period

Table A-12 summarizes the characteristics of the available data on average daily ingestion rates of vegetables, fruit, and grain based on the factors listed in *Exposure Factors Handbook* (U S EPA, 1997, Table A-7) The summary data on vegetables and fruit contain many of the characteristics relevant for application to risk assessment, with the exception of a distinction between leafy and non-leafy vegetables (Item 7) Data on grain ingestion rates are also very comprehensive, but do not provide any information regarding the homegrown fraction (Item 1)[1] In addition, a general observation for all of the survey data is that there is uncertainty in applying information based on short-term dietary patterns (i e , days or weeks) to estimate long-term ingestion rates (e g , years) among the U S population

Table A-12 Information on vegetable, fruit, and grain ingestion rates from Table A-7 that is reported by the *Exposure Factors Handbook* (U S EPA, 1997)

Item	Information	Vegetable	Fruit	Grain
1	Fraction homegrown	X	X	
2	Consumers only	X	X	X
3	Season-specific estimates	X	X	
4	Short-term and long-term average daily rates			
5	Region-specific estimates	X	X	X
6	Age-specific estimates	X	X	X
7	Portions of plant expected to have different concentrations[1]			

[1]Concentrations of elements in plants may vary depending on whether they grow above or below ground For example, vegetables may be divided into leafy and non-leafy (i e , root) categories

[1]Two basic approaches can be used to quantify exposures from homegrown commodities (1) Estimate the total consumption rates of each food category and multiply this value by the estimated homegrown fractions of each category, or (2) Use summary statistics for homegrown commodities The first approach was used for grain, in the absence of summary data on homegrown grain ingestion The second approach was used to develop probability distributions for vegetables and fruit

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A.1.3.1 PROBABILITY DISTRIBUTION FOR FRUIT, VEGETABLE AND GRAIN INTAKE RATES

For this analysis, probability distributions were generated from the empirical distribution functions reported in the *Exposure Factors Handbook* (U S EPA, 1997) For each data set, nine percentile values were reported (ranging from 1st to 99th) as well as the mean and maximum In addition, the intake rates were normalized to body weight and expressed in units of grams of food per kilogram body weight per day (g/kg-day) Despite the large sample sizes of the national surveys, the maximum ingestion rate reported from the survey may not represent a plausible maximum ingestion rate for the population Table A-13 presents the data used in this analysis, both on a g/kg-day basis and converted to g/day assuming 15 kg body weight for children and 70 kg body weight for adults

Table A-13 Empirical distributions of intake rates for vegetables, fruit, and grain as reported by the *Exposure Factors Handbook* (U S EPA, 1997) in g/kg-day, and converted to kg/yr

Percentile of ECDF	Vegetables			Fruit			Grain		
	Table[1] 13-33	kg/yr child	kg/yr adult	Table[1] 13-33	kg/yr child	kg/yr adult	Table[1] 12-1	kg/yr child	kg/yr adult
0 01	1 80E-03	0 01	0 04	5 50E-04	0 00	0 01	0 0	0 0	0 0
0 05	1 91E-02	0 10	0 47	5 66E-02	0 30	1 39	0 69	3 6	16 9
0 10	3 83E-02	0 20	0 94	8 82E-02	0 46	2 16	1 13	5 9	27 7
0 25	1 14E-01	0 60	2 79	2 87E-01	1 51	7 03	1 92	10 1	47 0
0 50	4 92E-01	2 58	12 05	6 88E-01	3 61	16 86	3 13	16 4	76 7
0 75	1 46E+00	7 67	35 77	1 81E+00	9 50	44 35	5 03	26 4	123 2
0 90	2 99E+00	15 70	73 26	4 75E+00	24 94	116 38	7 98	41 9	195 5
0 95	5 04E+00	26 46	123 48	8 54E+00	44 84	209 23	10 90	57 2	267 1
0 99	8 91E+00	46 78	218 30	1 45E+01	76 13	355 25	19 50	102 4	477 8
1 00	1 12E+01	58 80	274 40	1 84E+01	96 60	450 80	25 89	135 9	634 3

Unit conversion kg/yr = g/kg-day x average body weight x 0 001 kg/g x 350 day/yr, body weights for children and adults were assumed to be 15 kg and 70 kg, respectively

[1]*Exposure Factors Handbook* (U S EPA, 1997)

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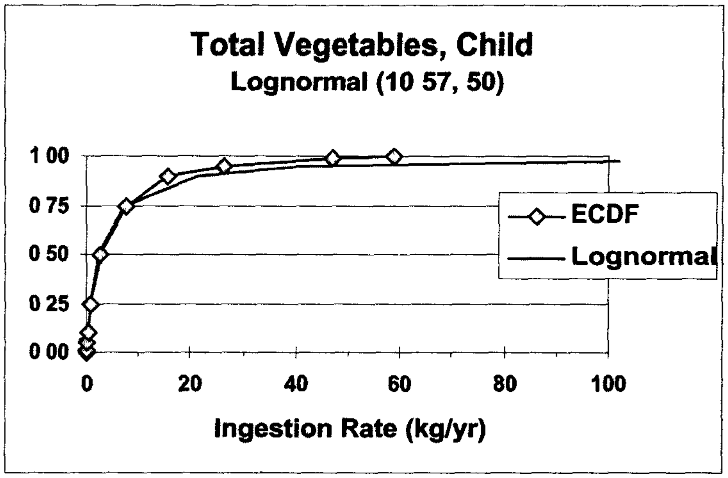

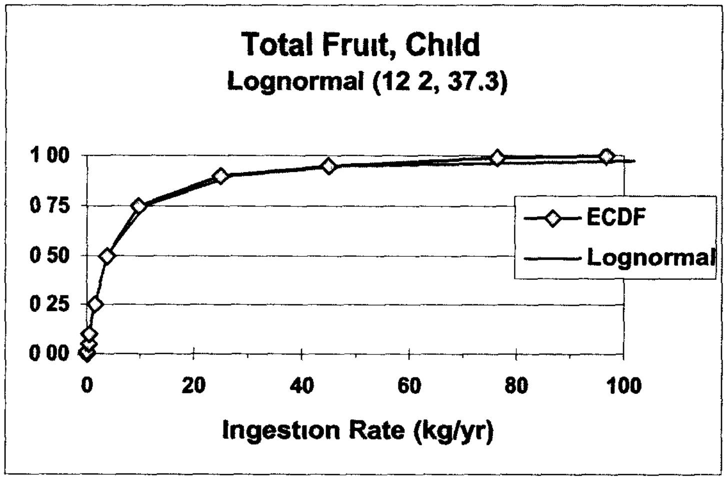

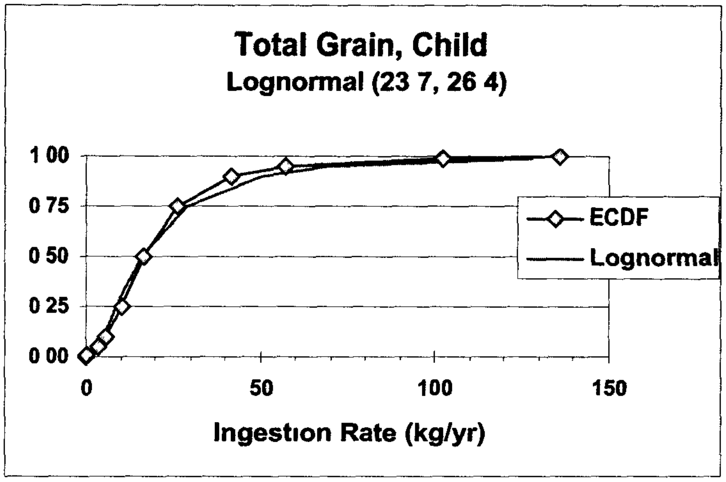

Figure A-9 Comparison of empirical and lognormal cumulative distribution functions for ingestion rates of vegetable, fruit and grain by children

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IR_food ~ Lognormal (mean, SD) kg/yr

The lognormal distribution is defined by two parameters Values for childhood ingestion rate of total vegetables are given below as an example

- arithmetic mean 10 57 kg/yr
- standard deviation 50 00 kg/yr

For this analysis, truncation limits were not applied By definition, the lognormal distribution is bounded at the low-end at 0 (i e , non-negative values), which is a reasonable lower limit for this variable

Empirical data can be used directly in a probabilistic risk assessment by specifying an ECDF Alternatively, the percentile values can be fit to a probability distribution Several continuous distributions were evaluated for this analysis based on visual inspection and goodness-of-fit statistics using @Risk (Palisades Corp) Although @Risk does provide goodness-of-fit statistics, these should be interpreted with caution given that goodness-of-fit techniques are typically applied to raw data values rather than percentile data Nevertheless, the Chi-Square and Kolmogorov-Smirnoff test statistics provide an additional metric for evaluating the relative fits of the observed percentile data to F(x), the percentiles of the hypothesized distribution Lognormal distributions provided an adequate fit for most of the summary data Results of graphical analysis and maximum likelihood parameter estimates are given below Table A-14 summarizes the distributions and parameter estimates used in the risk assessment

Table A-14 Summary of parameter values for lognormal distributions used to characterize variability in vegetable, fruit, and grain ingestion rates

Average Daily Ingestion Rates (kg/yr) by Plant and Age Group			
Plant	**Child (< 7 yrs)**	**Adult (7+ yrs)**	**Age-Adjusted[1]**
Vegetable, total	[10 57, 50]	[50, 240]	not used
Vegetable, leafy	[1 57, 7 45]	[7 45, 35 76]	[6 3, 28 6]
Vegetable, non-leafy	[9 00, 42 55]	[42 55, 204 24]	[35 8, 163 6]
Fruit, total	[12 2, 37 3]	[57, 174]	not used
Grain, total	[23 65, 26 4]	[110, 123]	not used
Non-leafy vegetable + fruit + grain	[21 4, 56 6]	[100 7, 268 3]	[84 8, 214 9]

[1]Age-adjusted = (6/30) x IR for child + (24/30) x IR for adult, age-adjusted values are used in RESRAD simulations only, and values are not needed for total vegetable, fruit, or grain

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A.1.3.2 UNCERTAINTIES IN THE PROBABILITY DISTRIBUTION

The summary tables given in the *Exposure Factors Handbook* (U S EPA, 1997) reflect a number of simplifying assumptions and statistical methods that may be important to understand in order to characterize the uncertainties associated with this exposure pathway These are briefly described below

Per capita vs. Consumers only – Consumers are defined as members of a household who reported consumption of the food item/group of interest during the survey period *Per capita* estimates reflect the combination of respondents who reported intakes during the study period (i e , consumers) and individuals who may consume a commodity in the future

Age-specific Estimates Based on Body Weight – Data are reported on a body weight-normalized basis (grams of food per kg body weight per day) To convert to an intake rate (g/day) for the risk assessment, it is necessary to multiply values by body weight (kg) For the Rocky Flats risk assessment, the target population is divided into two age groups—children and adults As summarized in the *Exposure Factors Handbook* (U S EPA, 1997), the average body weight for children ages 6 months to 6 years is approximately 15 kg (U S EPA, 1997, Table 7-3) and adults ages 18 to 75 years is approximately 70 kg (U S EPA, 1997, Table 7-2) These weights were applied to the data to generate age-specific distributions According to the *Exposure Factors Handbook* (U S EPA, 1997, pages 13-7 to 13-9), the average body weight of respondents (children and adults combined) was approximately 60 kg If exposure duration of 30 years is used in a risk assessment, with six years representative of children and 24 years representative of adults, the mean body weights used in this analysis match this result very closely

$$BW_{30\,yrs} = \frac{(6yrs \times 15kg) + (24yrs \times 70kg)}{30yrs} = 59kg$$

Extrapolation to long-term Estimates – The percentiles of the average daily intake were converted from the short time interval of 3 to 7 days to a long-term average by averaging the corresponding percentiles of each of four seasonal distributions for the same region (U S EPA, 1997, p 13-3) This approach reflects an assumption that each individual consumes at the same regional percentile levels for each week of a season, and each season of the year For example, an individual whose combined ingestion rate of vegetable, fruit, and grain is the 90th percentile for one week in the summer, would be assumed to also consume at the 90th percentile for all other weeks during the year

Summation of Ingestion Rates by Individual – Several methods may be used to estimate the average daily ingestion rates for multiple commodities (vegetable + fruit + grain) The preferred method would account for potential correlations for a given individual in their dietary preferences and choices of types of foods grown at home This correlation would be maintained if the summation were estimated at the level of the individual records from the survey data, rather than pooling data from the entire sample for each commodity, and summing at the population level In short, the average of the total ingestion rates reported by an individual is more representative than the sum of the average ingestion rates reported for each commodity

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Since such data were not available from the *Exposure Factors Handbook* (U S EPA, 1997), the total ingestion rate was calculated by summing the distributions for each commodity

Subpopulations for Vegetable and Fruit ingestion rate – Table 13-33 in the *Exposure Factors Handbook* (U S EPA, 1997) was used to derive probability distributions for average daily ingestion rates of total vegetables and fruit (i e , seasonally adjusted, consumer only, homegrown, West region, total vegetables, total fruit)

Subpopulations for Grain Ingestion Rate – Table 12-1 in the *Exposure Factors Handbook* (U S EPA, 1997) was used to derive a probability distribution for average daily grain ingestion rate (per capita, West region, total grains including mixtures) Data could be selected by age group, *or* by region for all ages combined, but there are no regional age-specific data For this analysis, distributions are based on data by region (i e , West) and average body weights for children and adults are used to derive age-specific distributions It is unclear how variability in ingestion rates among children compares with variability for adults

Homegrown Fraction for Grain – There are no data available on homegrown fraction of total grain ingestion rate The homegrown fraction would represent the family that harvests the grain at home in order to prepare grain products such as flour for breads This fraction is expected to be relatively low, as compared with homegrown fractions for vegetables (17% for gardeners, 31% for farmers) and fruit (10% for gardeners, 16% for farmers) (U S EPA, 1997) It was assumed that only 1% of the population grows and prepares grain products at home

Seasonal Variability for Grains – Seasonal patterns are thought to be a minor source of variability in grain consumption (U S EPA, 1997, p 12-1) because grains may be eaten on a daily basis throughout the year Therefore, the distribution based on short-term data is considered a reasonable approximation of the long-term distribution, although it will display somewhat increased variability (U S EPA, 1997)

Table A-15 Confidence ratings for homegrown vegetable, fruit, and grain ingestion rates (IR_veg, IR_fruit, IR_grain) for the Rural Resident scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	USDA and EPA review of National Survey Data	High
• Accessibility	Methods are described in detail in the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Reproducibility	Methodology is presented in the *Exposure Factors Handbook* (U S EPA, 1997) but information on questionnaires and interviews were not provided	Medium
• Focus on factor of interest	Elements of studies are focused on factors of interest for vegetables and fruit includes fraction homegrown, consumers only, season-specific, region-specific, and age-specific Uncertainties reflect extrapolation from short-term to long-term average and categorization of plant types in relation to soil-to-plant transfer factor Additional uncertainty for grain is lack of data on homegrown fraction	High for vegetable and fruit, Medium for grain

Considerations	Rationale	Rating
• Representativeness of study population	See above. Very representative for vegetable and fruit ingestion, but uncertainty in fraction homegrown for grain. Uncertainty in all data regarding long-term average dietary patterns.	High for vegetable and fruit, Medium for grain
• Primary data	Analyses are based on primary data.	High
• Currency	Vegetables and fruit: USDA NFCS 1987–1988 Grain: USDA CSFII 1989–1991 (*Exposure Factors Handbook*, U.S. EPA, 1997)	High
• Adequacy of data collection period	Respondents estimated intakes over a three-day period. Statistical methods used to extrapolate to long-term averages.	Low
• Validity of approach	Individual intakes inferred from household consumption.	Medium
• Study size	10,000 individuals and 4,500 households nationwide	High
• Characterization of variability	EPA reported in the *Exposure Factors Handbook* (U.S. EPA, 1997) nine percentiles of the empirical distribution function, which provided a reasonable visual fit with lognormal distributions. Parameters estimated with MLE methods, yielded very high coefficient of variation (~ 5) for vegetable intake. Uncertainty in upper bound—no truncation limit was applied. Uncertainty in treating distributions for vegetable, fruit, and grain as independent.	Medium
• Lack of bias in study design (high rating is desirable)	Non-response bias cannot be ruled out due to low response rate.	Medium
• Measurement error	Uncertainty in respondents' estimates of food weights.	Medium
Other Elements		
• Number of studies	One study of one survey period	Low
• Agreement between researchers	General agreement that data summarized by the *Exposure Factors Handbook* (U.S. EPA, 1997) is reasonable for use in risk assessment.	High
Overall Confidence Rating	Large sample size and very good representativeness for vegetable and fruit, which comprise the majority of the total homegrown intake. Uncertainty in response survey bias, choice of probability distribution, independence of vegetable, fruit, and grain, and extrapolation to long-term average.	Medium

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A.1.3 3 CONTAMINATED FRACTION, PLANT FOOD

It was assumed that 100% of the homegrown produce ingested was contaminated for both RESRAD and Standard Risk equation modeling

A.1.4 SOIL-TO-PLANT TRANSFER FACTORS (TF) FOR PLUTONIUM AND AMERICIUM

The risk and dose calculations handle plant transfer factors somewhat differently The risk calculations sum the individual plant ingestion sub-pathways, so that different plant transfer factors can be applied to each plant category (leafy vegetables, non-leafy vegetables and fruits, and grains) RESRAD needs a single value as an input for a soil-to-plant transfer factor

Dr Ward Whicker recommends basing root uptake values on results reported in a study at the Savannah River Plant (Whicker, et al , 1999) measured in terms of weight of dry plants per weight of dry soil The root uptake factor for non-leafy vegetables will be applied to fruits and grains as well These recent data suggest that plutonium uptake into plants is significantly lower than the default value used in RESRAD The working group incorporated these more recent plant transfer factors into the RSAL calculations

Table A-16 Plant transfer in dry plant weight per dry soil weight (derived from Whicker et al , 1999)

Plant Category	Pu-239/240	Am-241
Leafy vegetables	2 35x10^{03}	5 2x10^{02}
Non-leafy vegetables (average)	*2 5x10^{04}	4 5x10^{03}

*The discrepancy with the later value provided by Whicker (Whicker, 2001) of 1 9x10^{04} is due to a difference in averaging approaches and results in a slightly more conservative value

Conversion factors listed in Baes, et al , 1984, can be used to convert these values to wet plant weight per dry soil weight Wet plant weight is the form in which food consumption is reported and is the form required as input to the risk equations (the RESRAD code requires dry weight) These dry to wet-weight conversion factors are based on actual measurements of the weight of fresh plant tissue compared to the weight of dried plant tissue The Baes report listed an overall average value of 0 428, which is weighted based on U S production during the 1980's for each plant This heavily weights the overall average in favor of grains such as wheat, barley and rice, which are not common components of backyard gardens The working group also recognized that production-based weighting may change with time Therefore, the working group developed simple average values for each plant category, based on selected plants typically grown in Colorado An arithmetic average of 17 conversion factors for root vegetables, fruits, corn and peas is **0.16** and the average of conversion factors for three grains is **0.89** The reported conversion factor for leafy vegetables is **0.07** Converted uptake values are listed in the following table

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Table A-17 Plant transfer factors converted to wet plant weight per dry soil weight

PLANT CATEGORY	Pu-239/240	Am-241
Leafy vegetables	$1\ 6 \times 10^{04}$	$3\ 7 \times 10^{03}$
Non-leafy vegetables and fruits	$4\ 0 \times 10^{05}$	$7\ 2 \times 10^{-04}$
Grains[1]	$2\ 2 \times 10^{04}$	$4\ 0 \times 10^{03}$

[1]The value for grains applies only to EPA Risk Assessment Methodology and is not required as a RESRAD input

To develop radionuclide-specific soil-to-plant transfer factors for RESRAD input, the converted transfer factors have been weighted by the homegrown proportions for each plant category Based on data from *Exposure Factors Handbook* (U S EPA, 1997), dietary intake from leafy vegetables is approximately 15% and from non-leafy vegetables and fruits is 85% Because data are not available to distinguish the dietary proportion of grains, grains are not included in the plant transfer factor equations A working group assumption is that homegrown grains make up only 1% of the total grain consumption, so excluding grains will not significantly impact the result

Radionuclide-Specific Plant Transfer Factors

Pu-239/240 => $(1\ 6\text{x}10^{-04})(\ 15) + (4\ 0\text{x}10^{-05})(\ 85) = 5\ 8\text{x}10^{-05}$

Am-241 => $(3\ 7\text{x}10^{-03})(\ 15) + (7\ 2\text{x}10^{-04})(\ 85) = 1\ 2\text{x}10^{-03}$

These values compare with the current RESRAD default of $1\ 0\text{x}10^{-03}$ for both Pu and Am

A.1.5 SOIL-TO-PLANT TRANSFER FACTORS FOR URANIUM (TF_V AND TF_R)

Another variable that is unique to the Rural Resident land use scenario is the soil-to-plant (or plant/soil) concentration ratio The transfer factor term is used to estimate the concentration of a contaminant that is expected in edible foods based on the concentration in soil The literature was reviewed to develop a transfer factor term for uranium (U-234, U-235, and U-238) The ideal data set would characterize variability in transfer factor for each of the food categories defined for the ingestion rate variables (i e , vegetable, fruit, and grain) One transfer factor term could be developed for leafy or exposed vegetable crops (TF_v) while a second could be developed for root, reproductive or protected types of vegetable crops (TF_r) These estimates could then be weighted according to the fraction of the homegrown diet comprised of each food group

Numerous factors may contribute to variability in plant uptake, most notably soil characteristics such as soil type, pH, and moisture content, and plant types and plant parts (e g , leafy vegetables vs root vegetables) In addition, available data may be reported in either wet weight units or dry weight units Since exposures via food ingestion are based on consumption of a mass of food expressed in wet weight units, conversion factors may need to be applied to obtain wet weight

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values from dry weight values RESRAD and EPA's Risk Assessment Guidance for Superfund (RAGS) Standard Risk equations use different approaches to obtain an estimate of plant uptake in wet-weight units In RESRAD, inputs are expressed in wet-weight units, whereas in Standard Risk equations, plant uptake values are expressed in dry-weight units and multiplied by a dry-to-wet weight conversion (DWC) factor

Table A-18 gives the probability distribution for all food groups that were derived from the available literature A discussion of how the data from the literature were used to develop this distribution is provided following Table A-18 and the accompanying graphics in Figure A-10

Table A-18 Probability distribution for plant/soil transfer factors for uranium

Lognormal Distribution Parameters[3]	Wet Weight[1] Factor	Dry Weight[2] Factor (unitless)			
	All Food Groups	All Food Groups	Leafy Vegetables	Fruit, Root Vegetables	Cereals
AM	0 0019	0 0155	0 0206	0 0077	0 0068
SD	0 0029	0 0233	0 0209	0 0155	0 0046
95^{th} %ile	0 0064	0 0512	0 0576	0 0278	0 0155
GM	0 0011	0 0085	0 0144	0 0034	0 0056
GSD	2 97	2 97	2 32	3 57	1 86
AM of ln(x)	- 6 8355	- 4 7633	- 4 2392	- 5 6727	-5 1876
SD of ln(x)	1 0893	1 0893	0 8420	1 2712	0 6199

[1]Wet weight units for RESRAD model runs
[2]Dry weight units for Standard Risk equations See Figure A-10 for the lognormal probability density function and cumulative distribution function for all food groups
[3]Parameters arithmetic mean (AM), standard deviation (SD), geometric mean (GM), geometric standard deviation (GSD), percentile (%ile), natural logarithm of X (ln (x))

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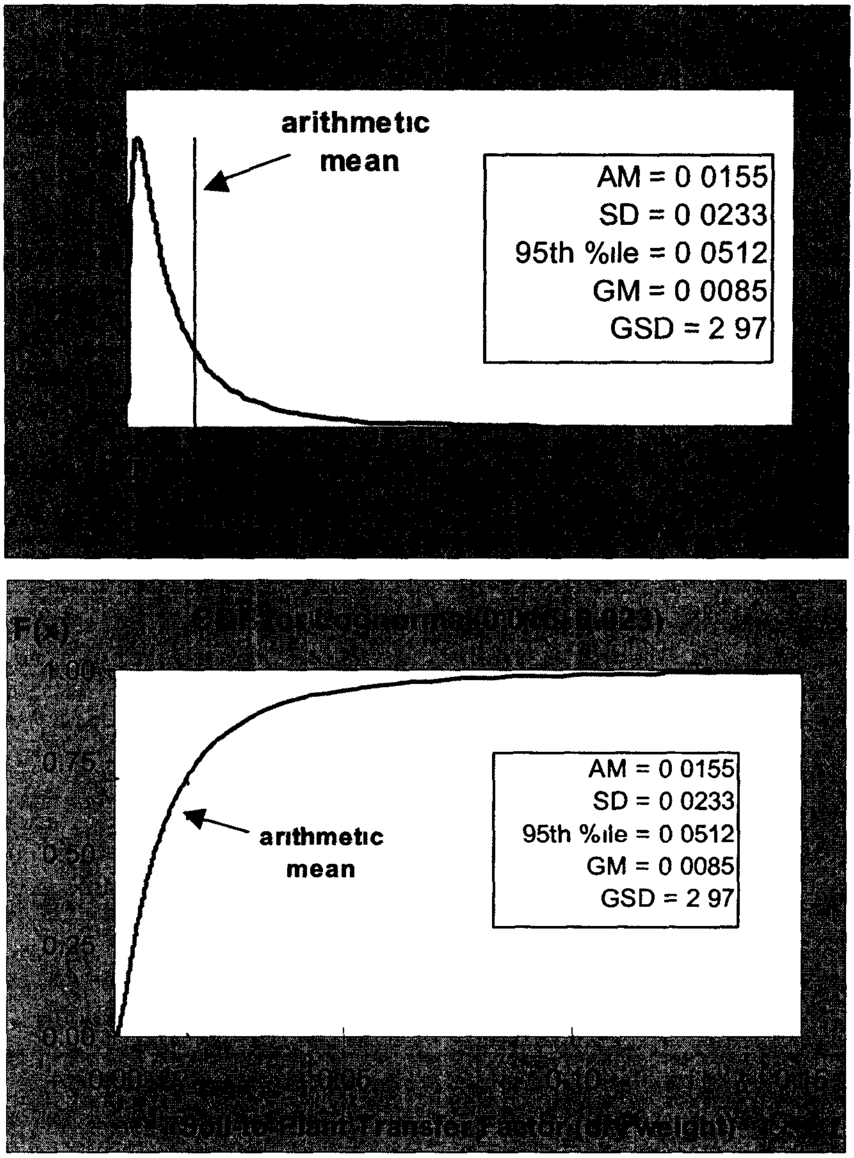

Figure A-10. Probability density function (PDF) and cumulative distribution function (CDF) views of the probability distribution characterizing variability in soil-to-plant uptake factors for uranium Parameters are given in dry weight units The AM (0 015) highlighted in each graphic corresponds with approximately the 70th percentile of the distribution See Table A-18 for a conversion to wet-weight units

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Several key studies and secondary references given were evaluated (Atomic Energy of Canada (AEC), 1988, Sheppard and Evenden, 1988, Sheppard and Evenden, 1989, CH2MHill, 1988, Mordvedt, 1994) An extensive literature review was not conducted, although some of the primary literature was reviewed to obtain additional information to support the assumptions

The available empirical data suggest that numerous factors may interact in a complex manner to control the availability of uranium in surface soil, and the uptake and translocation of uranium by plants Transfer factor values given by AEC (1988) and Sheppard and Evenden (1988) reports are presented below

Atomic Energy of Canada (AEC) Ltd. (1988) – This primary study gives transfer factor values in both dry weight (Table A-19) and wet weight (Table A-20) units for the following six crops spinach, potato (peel and flesh), blueberry (stems, leaves), corn (grain, stover), wild rice (grain and stem), and barley (grain, straw) As discussed below (transfer factor values by plant part), data were excluded for the following three crops, which were determined to be inedible for humans corn stover, blueberry stems and leaves, and barley straw Wild rice stems were not excluded because there are recipes for Asian soups that include rice stems

Data from AEC expressed in wet weight units were combined with data from Sheppard and Evenden (1988), converted to wet weight units The data yield a total of 11 individual transfer factor values for five crops Transfer factor values were combined by calculating the geometric mean by crop type For example, two values for potato peel (wet weight 0 020 in silt and 0 0077 in sand) yield a combined wet weight transfer factor value for potato peel of 0 012 These summary statistics were then presented in both wet weight and dry weight units for use in RESRAD and Standard Risk equations, respectively The methods used to DWC factors are explained below

Table A-19. Transfer factor values for uranium in units dry plant/dry soil (AEC, 1988)

Plant Part		clay	silt	sand	organic	Min	Geomean	Max
spinach		0 033			0 00790	0 0079	0 023	0 033
potato	peel		0 150	0 066		0 066	0 099	0 150
	flesh		0 019	0 002		0 002	0 006	0 019
corn	grain	< 0 01	0 00036			0 00036	0 00036	0 00036
	stover	0 0019	0 012			0 0019	0 005	0 012
blueberry	leaf			0 11	0 0028	0 0028	0 02	0 11
	stem			0 038	0 0039	0 0039	0 012	0 038
wild rice	grain		0 00051			0 00051	0 00051	0 00051
	stem		0 017		0 00073	0 0007	0 004	0 017
barley	grain	< 0 03	0 0021			0 0021	0 0021	0 0021
	straw	0 012	0 066			0 012	0 028	0 066
Min		0 0019	0 0004	0 0020	0 00073	0 0004	0 0004	0 0004
Geomean		0 0091	0 0042	0 0273	0 00091	0 0028	0 0063	0 0132
Max		0 0330	0 1500	0 1100	0 00790	0 066	0 099	0 150

Source Atomic Energy of Canada, 1988, Table 6

[1]Each value summarizes n = 3 (except for values in italics that are based on n = 1) but the summary statistic is not specified as the arithmetic or geometric mean of n=3

Table A-20 Transfer factor values for uranium in units fresh (wet) plant/dry soil (AEC, 1988)

Plant Part		clay	silt	sand	organic	Min	Geomean	Max
spinach		0 0063			0 00100	0 0010	0 0040	0 0063
potato	peel		0 020	0 0077		0 0077	0 012	0 020
	flesh		0 0035	0 00035		0 00035	0 0011	0 0035
corn	grain	< 0 01	0 000077			0 000077	0 000077	0 000077
	stover	0 00064	0 0035			0 00064	0 0015	0 0035
blueberry	leaf			0 056	0 0014	0 0014	0 009	0 056
	stem			0 018	0 00053	0 00053	0 0031	0 018
wild rice	grain		0 00035		< 0 06	0 00035	0 00035	0 00035
	stem		0 0073		0 00073	0 00073	0 0041	0 0073
barley	grain	< 0 03	0 0015			0 0015	0 0015	0 0015
	straw	0 0083	0 046			0 0083	0 020	0 046
Min		0 0006	0 0001	0 0004	0 00053	0 0001	0 0001	0 0001
Geomean		0 0032	0 0042	0 0072	0 00091	0 0009	0 0022	0 0046
Max		0 0083	0 0460	0 0560	0 00140	0 0083	0 020	0 0560

Source Atomic Energy of Canada, 1988, Table 9

[1]Each value summarizes n = 3 (except for values in italics that are based on n = 1) but the summary statistic is not specified as the arithmetic or geometric mean of n=3

Sheppard and Evenden (1988) – This study is an extensive literature review of transfer factor values for uranium and other radionuclides The authors report individual study data results in an appendix Each transfer factor value (in dry weight units) represents the geometric mean (GM) for a given study For some studies, additional summary statistics are provided, including the number of observations, the geometric standard deviation (GSD), transfer factor, and the minimum and maximum values Given this choice of summary statistics, presumably the authors suggest that a lognormal distribution is appropriate for characterizing variability in transfer factor values within a given study These parameters, the GM and GSD, can be used to calculate the corresponding 5[th] and 95[th] percentiles according to the following equation

$$TF_p = GM \times GSD^{z_p}$$

where,

TF_p = transfer factor corresponding to the p^{th} percentile
GM = geometric mean ratio
GSD = geometric standard deviation ratio
z_p = z-score corresponding to the p^{th} percentile of the standard normal distribution

The 5[th] percentile of the standard normal distribution (i e , $z_{0\ 05}$) is approximately -1 645, while the 95[th] percentile ($z_{0\ 95}$) is approximately + 1 645 When the study results are screened based on the criteria outlined in transfer factor Values by Plant part below (e g , remove studies in potted soils, include only edible plants such as cereals, leafy and root vegetables, and fruits and berry crops), approximately 25% (19 of 78) of the geometric mean transfer factor values (and other summary statistics) remain, representing approximately 10 studies and 200 measurements (see Table A-21)

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For 11 of the 19 transfer factor values, soil types were reported, 10 of the 11 values are from fine (clay) soils, and 1 of 11 (a leafy vegetable transfer factor value) is from a coarse (sand) soil

The last two studies summarized in Table A-21 reflect a combination of plant types There is uncertainty in applying these transfer factor values to one of three categories relevant to intake rates vegetables (v), fruit (b, for berry and fruit), or grain (c, for cereal)

For studies in which the GSD was not reported, a GSD for the same plant type (vegetable, fruit, cereal/grain) was applied The GSD for each plant type was calculated as the AM of the GSDs for crops categorized in that plant type The following are the average GSD values by plant type vegetative (2 40), fruit (3 67), and grain (1 86) The approach contributes to the uncertainty in the overall probability distribution calculated for each food class category In addition to using average GSD values to replace "missing values" in the Sheppard and Evenden (1988) study, the same set of GSD values was used to characterize lognormal distributions for the AEC (1988) study Specifically, the GM values in Table A-21 were combined with the appropriate GSD value to yield a probability distribution for each crop

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Table A-21 Subset of 19 soil transfer studies referenced by Sheppard and Evenden (1988, Appendix 1) Shaded values represent estimates of geometric standard deviation based on the average geometric standard deviation for other studies on the same plant type

Study		Soil		Plant		CR Values (dry plant / dry soil)								
Type	Subtype	Type	Conc (ppm)	n	Type	**GM**	**GSD**	**AM**	**SD**	**CV**	LGM	LGSD	min	max
f	agricul	n s		1	v	0 0040	1 65	0 0045	0 0024	0 53	-5 5	0 5		
f	plots	fine	20	1	v	0 012	2.40	0.0176	0 0189	1.07				
f	agricul	fine	60	3	v	0 0030	3 32	0 0062	0 0111	1 79	-5 8	1 2		
f	agricul	coarse	4	18	v	0 0012	2 23	0 0017	0 0016	0 95	-6 7	0 8		
c	agricul	n s	4	21	v	0 0029	2.40	0.0043	0.0046	1.07				
f	plots	fine	20	1	r	0 002	3.67	0.0047	0.0098	2.10				
f	agricul	fine	60	6	r	0 00027	3 67	0 0006	0 0013	2 10	-8 2	1 3		
c	agricul	n s	4	25	r	0 0005	3.67	0.0012	0.0024	2.10				
f	agricul	n s		1	b	0 010	4 06	0 0266	0 0658	2 47	-4 6	1 4		
f	plots	fine	20	1	b	0 003	3.86	0.0075	0.0171	2.28				
f	agricul	fine	60	8	b	0 0020	6 05	0 0101	0 0501	4 95	-6 2	1 8		
f	plots	fine	3	40	c	0 0076	1 49	0 0082	0 0034	0 42	-4 9	0 4		
f	plots	fine	0 9	12	c	0 014	1.86	0.0170	0 0116	0.68				
f	agricul	n s	6	8	c	0 0010	2 23	0 0014	0 0013	0 95	-6 9	0 8		
f	agricul	n s		1	c	0 0010	1.86	0.0012	0.0008	0 68			0 0005	0 002
f	agricul	fine	2 5	1	c	0 0014	1.86	0.0017	0.0012	0.68			0 0001	0 004
f	agricul	fine	8	21	c	0 00026	1.86	0.0003	0.0002	0.68			0 000001	0 0001
c	agricul	n s	4	21	cb	0 0006	1.86	0.0007	0.0005	0.68				
f	longterm	fine		15	crb - berry	0 0018	1 48	0 0019	0 0008	0 41			0 0005	0 003

Study types f = field, c = field with possible foliar contamination, Plant types b = fruit or berry, c = cereal, r = root vegetable, v = leafy vegetable
n s = not specified

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A.1.5.1 SINGLE DISTRIBUTION APPLICABLE ACROSS MULTIPLE SOIL TYPES

Literature on transfer factor values suggests that soil type can play an important role in determining the fraction of uranium that may be available for plant uptake (see Table A-22) Transfer factor values for radionuclides are generally element-specific, but not isotope-specific For uranium, transfer factor values can be considered equally applicable to U-234, U-235, and U-238 The predominant chemical species of uranium in soil is the uranyl ion, UO^{2+}_2 (Sheppard and Evenden, 1988) Thus, uranium will typically be more strongly bound (i e , lower transfer factor values) in soils with higher cation exchange capacity (i e , clays and organic soils) This is in contrast to mineral soils, in which organic complexes and colloids can increase the mobility of uranium (Sheppard and Evenden, 1988)

Table A-22 Factors that is likely to contribute to variability in soil/plant transfer factor for uranium

Factor	Effect on Plant/Soil Transfer Factor
Soil pH, carbonate content	High pH and low carbonate content tends to increase transfer factor, but effects will vary by plant
Soil phosphorus	High phosphorus concentrations tend to decrease transfer factor
Organic matter	Uranium mobility is reduced in higher organic matter soils, resulting in lower plant uptake and lower transfer factor, values for organic soils are 4 to 40 fold lower than mineral soils
Soil texture (clay, silt, sand)	Uranium mobility is reduced in finer textured soils (e g , clay), resulting in lower plant uptake and lower transfer factor
Chemical form	Predominant chemical species of uranium in soil is cationic, specifically the uranyl ion, UO^{2+}_2 , transfer factor values are lower in soils with higher cation exchange capacity (e g , clay)
Uranium concentration	Transfer factor values tend to decrease as concentrations in substrate (soil) increase, this may reflect, in part, the decreasing fractions of bioavailable uranium in soil as total uranium increases Transfer factor is really a direct measure of uranium available to the plant, rather than total uranium in the soil matrix
Plant type and part	Root crops tend to have higher transfer factor values than leafy vegetables or grains due to adsorption to cell walls, uncertainty stems from numerous sources of variability among plant types some plants can alter the microenvironment (e g , pH, Eh, solubility) within the bulk soil by exuding specific enzymes and chelates, metabolic byproducts and waste inorganic materials

The Rocky Flats workgroup concluded that soils at Rocky Flats are likely to be heterogeneous In addition, rural residents may use soil amendments in gardens Given that the Rural Resident future land use scenario could presumably result in backyard gardens being planted in a variety of soil types, there is no basis to prefer one soil type to another when developing inputs for risk assessment As a simplifying assumption, all of the available data on transfer factor values is considered to be potentially representative of conditions at Rocky Flats

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Of the 19 transfer factor values given by the Sheppard and Evenden (1998) study (Table 5 in study), 11 values are from fine soil, one is from course soil, and seven are unspecified Of the 11 transfer factor values given by the Atomic Energy of Canada (1988) report (Tables 2 and 3 in report), one is from clay, two are from organic, and seven are from silt/sand soils For the combined dataset, 13 values are representative of fine/clay soils that tend to bind uranium, and eight are from course/silt/sand soils for which uranium may be more readily available to plants A reasonable diversity of soil types is represented by the available data

A.1.5.2 TRANSFER FACTOR VALUES FOR URANIUM

The available empirical data suggest that numerous factors may interact in a complex manner to control the availability of uranium in surface soil, and the uptake and translocation of uranium by plants Table A-22 summarizes some of the factors that are likely to contribute to variability in transfer factor for uranium

When available data across all soil types and plant types are pooled, transfer factor values for uranium span several orders of magnitude Since some of these data may not be representative of potential environmental conditions and/or plants consumed by residents at Rocky Flats, it is important to establish criteria to screen the available data The following screening criteria were applied

- Exclude transfer factor values based on uranium mine tailings,
- Exclude studies with plants grown indoors (pots), subject to controlled environments (i e , artificial atmospheric and soil conditions),
- Exclude hydroponic studies, and
- Exclude studies on crops that are unlikely to be homegrown for human consumption (e g , leaves, stems, straw) Ideally, plant samples should be collected as plants reach the stage normally harvested for a food crop

Many of the studies that were excluded based on the above criteria had significantly higher transfer factor values, so applying the exclusion criteria tends to yield lower, but presumably more representative values

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Table A-23 Relationship between crop groupings reported for intake rates, dry-to-wet weight conversion (DWC) values, and transfer factor values for plant types/parts edible by humans

Transfer Factor Value	DWC (Baes et al , 1984)	DWC (Wang, Biwer, and Yu, 1993)	Intake Rates
Vegetative growth[1] (leaves, stems, and straw)	Leafy vegetables	Leafy vegetables	Vegetables
Reproductive, Storage, Growth[2] (fruits, seeds, and tubers)	Exposed produce	Fruits	Fruits
	Protected produce	Root vegetables	Vegetables
	Grains	Grains	Grains

[1] B_v term proposed by Baes et al , 1984
[2] B_r term proposed by Baes et al , 1984

Since different crop groupings are used in the risk assessment, a strategy is needed to relate crop groupings for intake rates, DWC factors, and transfer factor values Table A-23 summarizes the strategy used to relate intake rates, DWC values, and transfer factor values for the risk assessment For the intake rate estimates, food crops are grouped into three categories (1) vegetables, (2) fruits, and (3) grains These categories are based primarily on dietary considerations and national survey questionnaires DWC factors are discussed in detail below The methodology for calculating the final transfer factor values is also discussed below The generic transfer factor values are based on the AM DWC value for each category

A.1.5.3 DRY-TO-WET WEIGHT CONVERSION FACTORS

Transfer factor values are expressed in different units in the literature, including (1) pCi/g dry plant per pCi/g dry soil, (2) pCi/g fresh (wet) plant per pCi/g dry soil, and (3) pCi/g plant ash per pCi/g dry soil In risk assessment, human consumption rates of vegetable, fruit, and grain are typically expressed in units of kg of fresh (wet) weight of food item per unit time Therefore, for literature values expressed on a dry-weight basis, an approach is needed to convert to units of wet-weight RESRAD and Standard Risk equations use different approaches to obtain an estimate of transfer factor in wet-weight units

- **RESRAD** – inputs for transfer factor values are expressed directly in wet-weight units
- **Standard Risk Equations** – inputs for transfer factor values are in dry-weight units, and a DWC factor is used such that $TF_{wet} = TF_{dry} \times DWC$

The application of conversion factors can introduce a source of uncertainty in transfer factor values, especially if the conversion factors are calculated from a different plant type or plant part than the reported data

Some studies provide sufficient data to express the crop-specific estimate of transfer factor in either wet- or dry-weight units For these literature values, a DWC factor may not be needed for the Standard Risk equations For other literature values, a generic DWC term is needed that

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matches closely with the food category given by the ingestion rates For this analysis, three generic DWC values were estimated (1) DWC_{veg} – corresponds to the same crop groupings as the B_v term proposed by Baes et al (1984) for uptake in leaves, stems, and straws, but only for crops that may be consumed by humans, (2) DWC_r – corresponds to the same crop groupings as the B_r term proposed by Baes et al (1984) for uptake in reproductive and storage parts (fruits, seeds, and tubers), and (3) DWC_{grain} – for grain crops consumed by humans

Estimates for each DWC value were based on data summaries presented by three studies Baes et al (1984), Wang, Biwer, and Yu (1993), and Atomic Energy of Canada, Ltd (1988) Information on DWC given by each study is summarized below

Baes et al (1984) – Baes et al proposed four categories of crops based on food and feed production in the United States during the 1970's (1) leafy vegetables, (2) exposed produce, (3) protected produce, and (4) grains These crop groupings are slightly different than those for intake rates (see above) Baes' leafy vegetables category corresponds with the intake rate Category 1 (vegetables), and Baes' grain category corresponds with the intake rate Category 3 (grains) But, the "exposed produce" and "protected produce" categories both include a combination of fruits and vegetables A procedure is needed to estimate both the DWC and transfer factor values for fruits and vegetables on a crop-by-crop basis Table A-24 gives examples of DWCs for crops grouped by Baes et al, into the non-leafy vegetable categories Category 2 (exposed produce), Category 3 (protected produce), and Category 4 (grains) Baes et al does not provide DWC factors for Category 1 (leafy vegetables) Other literature sources do provide estimates

Wang, Biwer, and Yu (1993) – Table 2 of the DOE report, *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD*, presents DWC values in a modified grouping of foods categories (1) leafy vegetables, (2) root vegetables, (3) fruits, (4) grains, (5) forage, and (6) others It includes both the Baes et al (1984) data and NRC (1983) values Table A-25 in this appendix summarizes the DWCs relevant to the crops for human consumption Note that Wang et al (1993) choose to categorize asparagus as a leafy vegetable, whereas Baes et al included it in the "exposed produce" category

Atomic Energy of Canada, Ltd. (AEC, 1988) – As presented above (Tables A-19 and A-20), this primary study gives transfer factor values in both dry weight and wet weight units for the following edible crops spinach, potato (peel and flesh), corn (grain), wild rice (grain and stem), and barley grain Data were excluded for the following crops, which were determined to be inedible for humans corn stover, blueberry stems and leaves, and barley straw Wild rice stems were not excluded because there are recipes for Asian soups that include rice stems The ratio of wet/dry weight transfer factor values were calculated to estimate DWC (Table A-26)

The geometric mean (GM) DWC values for each category among all three studies are strikingly consistent as shown in Table A-27

TF Values – Baes et al. (1984) – Baes et al proposed two groupings for transfer factor values, based more on physiologic plant characteristics than on dietary food categories (1) B_v – vegetative growth (leaves, stems, and straws), and (2) B_r – nonvegetative growth (reproductive and storage parts such as fruits, seeds, and tubers) According to Baes et al leafy vegetables are the only group of food crops for which B_v is the appropriate category of transfer factor values Thus, B_r is the appropriate category of transfer factor values for the other three food categories

Transfer factor Values – Wang, Biwer, and Yu (1993) – Table 3 of the DOE report suggests that transfer factor values should be categorized into two food classes for human consumption Category k = 1, for root vegetables, fruits, and grain, and Category k = 2, for leafy vegetables

Table A-24 DWC factors for selected food crops[1]

Crop Type	DWC		Crop Type	DWC
Exposed Produce (weighted average = 0.126)				
Apple	0 159		Pear	0 173
Asparagus	0 070		Plums and Prunes	0 540
Bush berries	0 151		Sweet pepper	0 074
Cherry	0 170		Snap Bean	0 111
Cucumber	0 039		Squash	0 082
Eggplant	0 073		Strawberry	0 101
Grape	0 181		Tomato	0 059
Peach	0 131			
Protected Produce (weighted average = 0 222)				
Crop Type	**DWC**		**Crop Type**	**DWC**
Bean (dry)	0 878		Peas	0 257
Cantaloupe	0 060		Potato	0 222
Carrot	0 118		Sugar beet	0 164
Grapefruit	0 112		Sugarcane	0 232
Lemon	0 107		Sweet corn	0 161
Onion	0 125		Sweet potato	0 315
Orange	0 128		Tree nuts	0 967
Peanut	0 920		Watermelon	0 079
Grains (weighted average = 0.888)				
Barley	0 889		Rye	0 890
Corn (for meal)	0 895		Soybean	0 925
Oats	0 917		Wheat	0 875

[1]Source Baes et al , 1984, Table 2 3 To convert to wet weight, multiply the transfer factor value (dry plant/dry soil) by the conversion factor $TF_{wet} = TF_{dry} \times DWC$

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Table A-25 Dry-to-wet weight conversion factors for selected food crops

Crop Type	Baes et al. (1984)[1]	AEC (1988)[2]	NRC (1983)[1]	Crop Type	Baes et al (1984)[1]	AEC (1988)[2]	NRC (1983)[1]
Leafy Vegetables (average = 0.09)							
Asparagus	0 070	–	0 083	Spinach	–	0 172	0 083
Cabbage	–	–	0 077	Broccoli	–	–	0 110
Cauliflower	–	–	0 083	Brussel sprout	–	–	0 147
Celery	–	–	0 063	Kale	–	–	0 125
Lettuce	–	–	0 050	Turnip green	–	–	0 100
Rhubarb	–	–	0 053	--	–	–	–
Root Vegetables and Fruit (average = 0.15)							
Apple	0 159	--	0 149	Onion	0 125	–	0 116
Apricot	–	–	0 147	Orange	0 128	–	0 141
Banana	–	–	0 244	Peach	0 131	–	0 109
Beet	–	–	0 127	Pear	0 173	–	0 167
Sugar beet	0 164	–	–	Pepper	0 074	–	0 067
Blackberry	–	–	0 156	Pineapple	–	–	0 147
Blueberry	–	–	0 167	Plum	0 540	–	0 189
Bush berries	–	–	0 151	Potato	0 222	0 152	0 222
Cantaloupe	0 060	–	–	Pumpkin	–	–	0 084
Carrot	0 118	–	0 118	Sweet potato	0 315	–	0 294
Cherry	0 170	–	0 196	Radish	–	–	0 056
Sweet corn	0 261	0 214	–	Raspberry	–	–	0 175
Cucumber	0 039	–	–	Squash	0 082	–	0 060
Eggplant	0 073	–	–	Strawberry	0 101	–	0 101
Fig	–	–	0 227	Tomato	0 059	–	0 067
Grape	0 181	–	–	Turnip	–	–	0 085
Grapefruit	0 112	–	0 116	Watermelon	0 079	–	–
Lemon	0 107	–	–	Yam	–	–	0 263

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Crop Type	Baes et al. (1984)[1]	AEC (1988)[2]	NRC (1983)[1]	Crop Type	Baes et al (1984)[1]	AEC (1988)[2]	NRC (1983)[1]
Graın (average = 0.87)							
Barley	0 889	0 714	–	Rye	–	–	0 890
Corn (for meal)	0 895	–	–	Soybean	–	–	0 925
Oats	0 917	–	–	Wheat	–	–	0 875
Rıce	–	0 843	–	–	–	–	–
Other Crops (average = 0 34)							
Green bean	–	–	0 100	Pea	0 257	–	0 169
Lıma bean	–	–	0 322	Peanut	0 920	–	0 169
Chestnut	–	–	0 476	–	–	–	–

[1]Source Baes et al , 1984, Table 2 3–values for non-leafy vegetables To convert to wet weıght, multıply the transfer factor value (dry plant/dry soıl) by the conversıon factor $TF_{wet} = TF_{dry} \times DWC$
[2]Source Atomıc Energy of Canada, 1988, Table 9 DWC calculated from $DWC = TF_{wet}/TF_{dry}$

Table A-26. Dry-to-wet weıght conversıon factors based on Atomıc Energy of Canada (1988) study, edıble parts of plant only[1]

DWC Category Baes et al. (1984)	Plant Part	Summary Statistics by Crop			Mean of GM by Category
		Min	GM	Max	
Leafy vegetable	spınach	0 127	0 172	0 191	0 172
Root vegetable, Fruıt	potato, peel	0 117	0 125	0 133	0 152
	potato, fresh	0 175	0 180	0 184	
Graın	corn, graın	0 214	0 214	0 214	0 654
	wıld rıce, graın	0 686	0 686	0 686	
	wıld rıce, stem	1 000	1 000	0 429	
	barley, graın	0 714	0 714	0 714	

[1]Non-edıble plant parts were excluded, ıncludıng corn stover, blueberry stems and leaves, and barley straw GM = geometrıc mean Values are ratıos (wet weıght/dry weıght) for each summary statıstıc, so the magnıtude of the ratıo ıs not necessarıly ın order of mın < GM < max Of greater relevance ıs the mean of GM's by category

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Table A-27 Cross references for geometric mean dry weight conversion factors (DWC)

Study	Table Reference	DWC_{veg}	DWC_{root}	DWC_{grain}
Baes et al (1984)	Table A-24	0 13	0 22	0 89
Wang, Biwer, and Yu (1993)	Table A-25	0 09	0 15	0 87
AEC (1988)	Table A-26	0 17	0 15	0 65
Value used in this Analysis[1]		0 10	0 20	0 80

[1]Approximately the AM of the values given by each of the three studies

A.1.5 4 PROBABILITY DISTRIBUTION AND POINT ESTIMATES FOR TRANSFER FACTOR TERM

The following key assumptions were made in developing the overall probability distributions summarized in Table A-28

- Transfer factor values for each individual study can be characterized by a lognormal distribution,
- Transfer factor values can be combined into vegetative fractions and reproductive/storage/growth fractions of plants, variability in these categories is also characterized by a lognormal distribution, and
- A single, overall probability distribution can be developed based on the relative contributions of vegetables, fruit, and grain to total homegrown food ingestion

The motivation for obtaining one final distribution to characterize the transfer factor term is to provide a consistent approach in both the RESRAD and Standard Risk equations Otherwise, for the Standard Risk equations, variability in transfer factor could be incorporated into the analysis by plant category

A total of 19 distinct lognormal probability distributions were developed from the Sheppard and Evenden (1988) data, and an additional eight lognormal distributions were developed from the AEC (1988) data using average GSD estimates from Sheppard and Evenden (1988) The combined set of 27 probability distributions was divided into one of three categories of intake rates, as outlined in Table A-23 The final groupings of lognormal distributions for transfer factors are given in Table A-28 Transfer factor is expressed in wet weight units

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Table A-28 Parameters of lognormal distributions for transfer factors (wet weight) compiled by food category Final row gives the average of the (GM, GSD) statistics used to derive the overall distribution

Leafy Vegetable (n = 7)		Fruit (n = 9)		Grain (n = 10)	
GM	**GSD**	**GM**	**GSD**	**GM**	**GSD**
0 0008	1 65	0 0004	3 67	0 00608	1 49
0 0024	2 40	0 00005	3 67	0 0112	1 86
0 0006	3 32	0 0001	3 67	0 0008	2 23
0 0002	2 23	0 002	4 06	0 0008	1 86
0 0006	2 40	0 0006	3 86	0 00112	1 86
0 004	2 40	0 0004	6 05	0 00021	1 86
0 001	1 86	0 00126	1 48	0 0005	1 86
		0 001	3 67	0 00035	1 86
		0 000008	1 86	0 004	1 86
				0 020	1 86
Arithmetic Means					
0 00144	2 32	0 00069	3 57	0 00447	1 86

The final probability distributions given for each food category were weighted by the point estimates derived for age-adjusted average annual intake rates of each homegrown food

Homegrown vegetables	42 1 kg/yr (**46.3 %**)
Homegrown fruit	48 0 kg/yr (**52.7 %**)
Homegrown grain	0 9 kg/yr (**1.0 %**)
Total	91 0 kg/yr (100 0 %)

Thus, applying the weighting factors for all food categories yields a probability distribution for soil-to-plant transfer factor for uranium as follows, defined by parameters (GM, GSD)

Wet weight   Lognormal (0 0011, 2 97)
Dry weight   Lognormal (0 0085, 2 97)

The dry weight parameters were calculated by dividing the GM transfer factor values in Table A-28 by the corresponding DWC values given in Table A-27 These parameters can be converted to the alternative expression for the lognormal distribution using the arithmetic mean (AM) and standard deviation (SD)

Wet weight   Lognormal (0 0019, 0 0029)
Dry weight   Lognormal (0 0155, 0 0233)

Finally, a third alternative expression for the lognormal distribution uses the AM and SD of the log-transformed values

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Wet weight Lognormal (- 6 8355, 1 0893)
Dry weight Lognormal (- 4 7633, 1 0893)

The input for RESRAD would be the probability distribution corresponding to wet weight units for the log-transformed values **Lognormal (-6.8355, 1.0893)** The point estimate is based on the corresponding 95th percentile of this distribution, equal to 0 0063 The input for the risk-based approach would be the probability distribution corresponding to dry weight units with parameters (AM, SD) **Lognormal (0.0155, 0 0233)** The point estimate (95th percentile) is equal to 0 0513

A.1.6 EXTERNAL GAMMA SHIELDING FACTOR

The External Gamma Shielding Factor is the ratio of the external gamma radiation level indoors on site to the radiation level outdoors on site It is based on the fact that a building provides shielding against penetration of gamma radiation The previous Superfund Risk Assessment guidance (U S EPA, 1991b) used a default value of 0 8 for the shielding factor for gamma radiation to reflect shielding from building materials A shielding factor of 0 8 implies that an individual would receive 80% of the gamma dose available to someone outdoors This value was based on empirical studies of the attenuation of natural background radiation (including terrestrial sources, highly penetrating cosmic rays, and radiations emitted by the building materials themselves) The default value was recently revised to 0 4 in the *Soil Screening Guidance for Radionuclides Technical Background Document* (U S EPA, 2000) The basis for the revision is a review of newer literature, including studies of shielding from fallout and from nuclear power plant releases This review of additional studies is summarized in the EPA report, *Reassessment of Radium and Thorium Soil Concentrations and Annual Dose Rates* (U S EPA, 1996) In addition to the incorporation of additional information, the new default value is lower because it considers only the terrestrial sources of natural background and excludes the cosmic ray and building material sources This more correctly assesses the shielding afforded by the building from contamination in soil Based upon this more recent work, the working group selected the value of 0 4 for this parameter

A.1.7 INDOOR DUST FILTRATION FACTOR

The working group decided that there was insufficient information to develop a probability distribution for this variable A point estimate of 0 7 was used for the Rural Resident scenario, which assumes that the resident will spend time indoors where windows and doors will be open during summer months This is an average of the 0 4 indoor dust filtration factor described in *Soil Screening Level Guidance for Radionuclides* (U S EPA, 2000) and an outdoor value of 1 0

A.1.8 INDOOR/OUTDOOR TIME FRACTION

The indoor/outdoor time fraction refers to the fraction of the exposure period that is spent indoors and outdoors For the Office Worker scenario, the working group assumed that 100% of the office worker's exposure period (8 hours/day) is spent indoors Similarly, for the Open Space User scenario, the exposed population is outdoors 100% of the time

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For the Rural Resident scenario risk calculations, the working group referred to U S EPA Exposure Factors Handbook (U S EPA, 1997) Table 15-131, which reports the following 75^{th} percentiles for time indoors and outdoors per day 1235 minutes indoors and 210 minutes outdoors Given that there are 1,440 minutes in a day (24 hrs x 60 min/hr), the sum of the indoor and outdoors times equals approximately one day (1,445 minutes) Therefore, the following calculations yield the fractions used for the Rural Resident scenario

Indoors	210 min / 1,445 min = 0 145, rounded up to 0 15
Outdoors	1,235 min / 1,445 min = 0 8547, rounded down to 0 85

For the Wildlife Refuge Worker scenario, the working group used professional judgment to estimate that a wildlife refuge worker would spend half of the workday outdoors, and half indoors (i e , time fractions are 0 50 for each)

The working group decided that there was insufficient information to develop a probability distribution for this variable

A.1.9 MASS LOADING

Mass loading is a sensitive parameter in the RESRAD and EPA Standard Risk Methodology calculations While a great deal of mass loading data are available from monitors stationed in the vicinity of the site, these data appear to be more representative of regional fugitive dust influences than they are of site-related activities The exact scenarios being considered, from an air quality perspective, are not documented in previous data either from the site or elsewhere, and thus historical data cannot be used directly to infer either a point estimate or probabilistic mass loading appropriate to these scenarios Instead, the working group examined other sources of information from which to derive a mass-loading estimate, starting with the local data as a basis

The working group was able to derive a great deal of information from EPA's *"Compilation of Air Pollutant Emissions Factors"* (AP-42) (U S EPA, 1995) regarding several sources whose influence might be considered when developing a mass loading distribution for the RSAL calculations Emission sources or activities that were examined included garden tilling, use of recreational vehicles/horses, and fugitive dust due to passive wind-blown disturbance of soil The latter influence was examined in detail, including the modifying influences of prairie fire and precipitation The wind-blown dust that would be an aftermath of a widespread prairie fire was characterized using site-specific wind tunnel measurements

Once the behaviors of these source influences were characterized, the emission characteristics were integrated into a model that describes the frequency of occurrence and the effect of each source influence on the airborne soil-mass concentrations, i e , the mass loading The sections that follow describe the various source influences, the method used to integrate those influences into a frequency distribution describing mass loading, and the mass loading itself

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A.1.9.1 MASS LOADING INFLUENCES

Garden Tilling – In the Rural Resident scenario and in the Wildlife Refuge Worker scenario there exists a potential for some gardening-type activities In both cases, the activity would be limited to relatively small areas of the site In the Wildlife Refuge Worker scenario, this activity would not be expected to occur on contaminated soil However, under a case of failed institutional controls as in the Rural Resident scenario, gardening could occur on such soils The rural resident is assumed to reside on a relatively small plot of approximately five acres, all contaminated The working group proposed that as much as one acre of that land might be gardened The area would be prepared for the crop through several tilling cycles and the remains of the crop would be turned under at the end of the growing season AP-42, Section 11 of the fourth edition (U S EPA, 1985) provides emission calculations for such activities
The emission factor for agricultural tilling depends on several individual parameters, the silt content of the soil, the maximum particle size of interest, the tillage acreage and the number of times tilled in the period of interest For our purposes, the silt content is 50% (Kaiser-Hill, 2000) and the particles of interest are those less than 10 μm diameter, i e , those that can be readily inhaled during the activity The tilled acreage is one acre with three tilling cycles in a year The resulting increase in emissions is comparable in magnitude to the typical emissions from wind-blown fugitive dust off the same surface when covered with normal prairie vegetation, in other words, the mass loading is increased no more than a factor of two Considering that irrigation of the vegetable crop will actually result in fewer emissions than a normally unirrigated surface, the factor of two is considered a reasonable limit on increased emissions over the crop year

Recreational Vehicle/Horses – The working group considered the possibility that horses or light recreational-type utility vehicles might be operated on the site Such activity could constitute a dust emission source for the RSAL mass-loading calculation Fugitive dust emissions from horses were not found characterized in the literature, however, dust emissions from treaded vehicles are If one considers a horse to be similar to a light recreational utility vehicle, or is simply interested in the vehicle emissions, then this calculation applies Since these activities, or others very similar, could be associated with any of the scenarios being characterized in these RSAL calculations, this assessment is applicable to each of them

Consider the parameters needed to estimate light utility vehicle emissions, they are the mass of the vehicle, the number of surfaces in contact with the soil, the average speed of the vehicle, and the distance traveled (U S EPA, 1995, page 13 2 2) As a surrogate, a horse and rider may have a mass of about 400 kg, have four surfaces in contact with the soil (repetitive hoofed contact with the ground is not unlike repeated cleated contact with the ground from a vehicle tread), travel at an average speed of about five miles per hour, and exercise for about half an hour per session (not atypical of a utility farm vehicle, itself) If the vehicle (horse) were operated this way twice per week, the expected emissions from such an activity would be approximately 13 kg/yr, about one-third the emissions from fugitive dust from a five-acre area in the absence of any soil disturbance Even with daily activity, the emissions would be comparable

Considering the combined effects of gardening and recreational vehicle/horseback riding, the average mass-loading in the area around the activities might be expected to increase by as much as a factor of two compared to the fugitive emissions that would be present without such activities The working group took this factor into account when building the mass-loading distribution, assuming that such activities would occur with the same probability in any single year

Fugitive Dust Under Normal Conditions at Rocky Flats – Rocky Flats experiences nearly continuous winds, varying in speed from near calm (infrequently) to more than 40 m/s on some occasions in the late winter and early spring The median annual average wind speed at the site is about 4 2 meters per second, based on more than 25 years of site-specific meteorological data One of the predictable influences of these sustained winds is a relatively large contribution to mass loading from wind-blown soil erosion Related to this is the observation that the majority of radionuclide emissions from the site come from the resuspension of contamination attached to soil particles, mostly from the eastern lip of the Industrial Area and the eastern and southeastern Buffer Zone of the site Very little of the observed emissions originate from the building stacks

Effect of Prairie Fire on Contaminant Resuspension – Concern was raised during the independent assessment performed by RAC of the 1996 RSAL that a prairie fire at the site could have considerable influence on the amount of soil eroded into the air following such a fire As a result of this concern, and the recognition that no data could be found in the literature that characterize the post-fire effects of a prairie fire, the site engaged Midwest Research Institute (MRI, 2001a, b) to perform wind-tunnel-based soil erosion measurements The measurements were performed on burned vegetated surfaces following a controlled burn conducted at the site in CY2000, and a subsequent, unrelated lightning-caused fire in the same year The erosion potential was measured at several intervals over the months immediately following the controlled burn to develop a profile that characterizes the rate of recovery of the burned area It was postulated that the burned area would have a much higher erosion potential in the first few days or weeks following the fire, but would exhibit continuously improving erosion inhibition as the vegetation grew back over the burned, denuded soil

The results of the wind-tunnel measurements confirmed that the erosion potential would decrease rather quickly with time following the controlled burn Effects of soil moisture on erosion potential were also evident in the same set of measurements The wind-tunnel work has been described in detail in two final test reports from MRI (MRI, 2001a and MRI, 2001b) The analysis of these data is described below

The MRI controlled burn report (MRI, 2001a) provides three sets of post-fire measurements to demonstrate the effects of vegetative recovery on the erosion potential of the surface soils When these erosion curves are compared, they suggest the wind-blown erosion is reduced to less than one-third of its maximum within three or four months of the fire If this behavior is fitted to a simple power curve, shown as Figure A-11, the results show that the burned area will recover its dust mitigation characteristics completely within 6 to 12 months following the fire, except for the possible mitigating effects of thatch which will not be present within such a short period (The presence of thatch would be more important in areas denuded of growing vegetation as might occur during a drought, and would not tend to be an important factor in overgrown areas)

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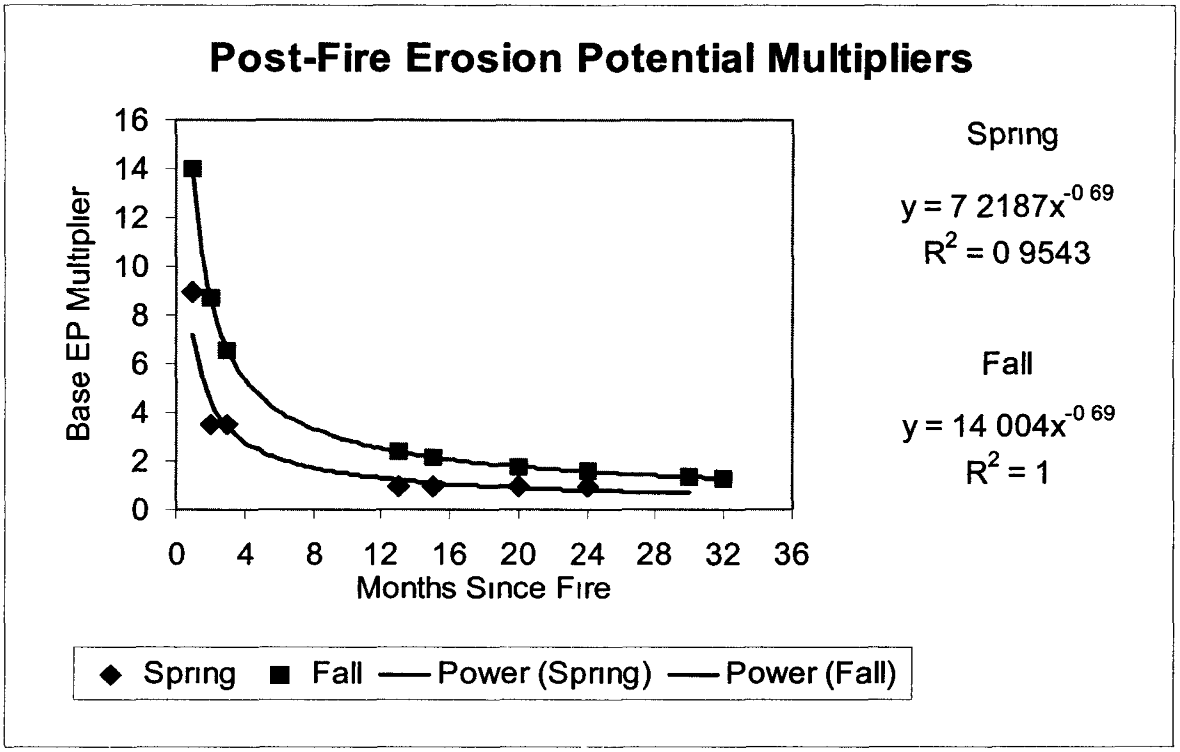

Figure A-11. Mathematically fitted erosion-potential recovery curves following spring or fall prairie fires at Rocky Flats

Had this same fire occurred in the fall or early winter, the recovery period would have been lengthened The resulting mass-loading multiplication factor associated with these late-season fires is 4 74, as derived from the fall curve shown in Figure A-11 This factor was estimated using the same arguments as with the spring fire but interpolated over a period of 24-months, to account for the arrested period of growth during the winter months immediately following the late-season fire The same precipitation adjustments were applied to each month for the first year of recovery, and the average emission factor was calculated The initial emissions from a late-season fire will be somewhat higher than for the spring fire, evidenced by the wind tunnel recovery curve for the June measurements (taken during a relatively dry period, representative of soil conditions in Fall)

Details of how these curves were used to derive the empirical mass-loading multipliers can be seen in Table A-29 In order to calculate an annual average increase attributable to a prairie fire, each month's emission potential (from the fitted curve) is then adjusted by a factor that accounts for the expected precipitation for that month and the average emission potential for all periods are averaged The average increase in emissions associated with this rapid recovery is approximately 2 5 times the emissions associated with similar adjacent areas of unburned grasslands used as a control on the measurements, as indicated in Table A-29 The factor actually used in the mass-loading calculations is 2 51

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Table A-29 Calculation of mass loading multiplier, bolded numbers are results for spring and fall burns, respectively

Time (months)	Spring Monthly Contribution	Fall Monthly Contribution	Annual Precipitation Factor	Spring Monthly Contribution w/precipitation	Fall Monthly Contribution w/precipitation
1	0 75	1 17	0 926	0 69	1 08
2	0 29	0 72	0 926	0 27	0 67
3	0 29	0 55	0 926	0 27	0 51
4	0 23	0 45	0 926	0 21	0 42
5	0 20	0 38	0 926	0 18	0 36
6	0 17	0 34	0 926	0 16	0 31
7	0 16	0 30	0 926	0 15	0 28
8	0 14	0 28	0 926	0 13	0 26
9	0 13	0 26	0 926	0 12	0 24
10	0 12	0 24	0 926	0 11	0 22
11	0 12	0 22	0 926	0 11	0 21
12	0 11	0 21	0 926	0 10	0 19
	2 72	5 12		**2.51**	**4.74**

Effects of Precipitation – In the preceding section, the effects of precipitation on erosion potential for airborne fugitive dust emissions were described briefly, concerning in particular the mediating effects of snow cover AP-42 describes similar effects for rainfall precipitation As a means of estimating fugitive emissions, days with rain exceeding 0 01 inches are treated as though their emissions are zero As we have described previously, days with snow cover can be treated the same The question might be raised then—what is the effect on fugitive dust during periods of drought? (Periods of excessive rainfall were also examined, but their influence is not considered as important to the discussion as periods of deficient rainfall)

Literature from The National Drought Mitigation Center, headquartered at The University of Nebraska – Lincoln, (NDMC, 1995), suggests that the onset of drought is marked by a sustained period with rainfall at levels 75% or less compared to that normally experienced This is preferably based on a 30-year or greater meteorological history At Rocky Flats, a 37-year meteorological history has been reviewed and summarized (EG&G, 1995) and provides a good basis for assessing the potential effects and frequency of occurrence of drought-like conditions In addition, data from state publications and databases (Colorado State University, 2000) provide insight into the occurrence of drought in the State, as a whole From site-specific meteorological data, we were able to infer that Rocky Flats could experience drought-like conditions about 20% of the time During those periods, there are roughly 40% fewer days with rainfall that may exceed 0 01 inches, compared to a median estimate of 78 days with such amounts This suggests that the dry conditions might be characterized by emissions that are increased by about 11% based on this calculation that inhibits emissions on days with greater than 0 01 inches of rain The number used to characterize this condition in the mass loading calculation was 14%, based on a linear fit to the precipitation data with one biased month removed (The month of May, with its extreme precipitation, does not appear to be representative of the typical behavior for this parameterization) It is worth noting, that the emissions would be expected to increase by about 27%, based on this limited hypothesis, should there be no rainfall, and no other

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contribution to increased emissions Zero rainfall was not considered a feasible condition to assess

To summarize, the drought-like conditions that might be observed to increase emissions at Rocky Flats would occur about 20% of the time and would result in emissions increased by about 11% or more Because of the uncertainty in this estimate due to one apparently non-representative month, the emissions were considered to increase by 14%

A.1.9.2 BUILDING A MASS-LOADING DISTRIBUTION

The information described above was combined with site-specific and statewide Particulate Matter (PM)-10 data to build mass loading distributions for both PM-10 and Total Suspended Particulates (TSP) air mass concentrations

- *Site-specific PM-10 and TSP mass concentration* – Appendix F provides the site-specific PM-10 data obtained from the Colorado Department of Health and Environment (CDPHE) five-station network The data are described by a minimum concentration of 9 4 $\mu g/m^3$, a maximum concentration of 16 6 $\mu g/m^3$ and a median concentration of 11 6 $\mu g/m^3$ Data from the site's Radiological Air Monitoring Program (RAAMP) network have been used to relate the PM-10 data to TSP data, specifically the relative distribution of plutonium between PM-10 and TSP Data collected since 1994 show a relatively consistent trend with the larger TSP fraction having about 2 5 times the activity of the airborne material smaller than 10 μm aerodynamic diameter

- *Statewide PM-10 mass concentrations* – Appendix F also provides a six-year set of PM-10 mass concentrations from throughout Colorado These data are representative of air quality in areas most likely to be impacted by industrial, agricultural and urban emissions They could be considered as a probable representation of the likely extremes of air quality that might be observed at Rocky Flats in the future, should the area be developed residentially or commercially These PM-10 mass concentrations are described by a distribution whose minimum is 6 7 $\mu g/m^3$, maximum is 51 4 $\mu g/m^3$, and median concentration is 20 3 $\mu g/m^3$

- *Building a frequency distribution* – Existing data do not provide an adequate surrogate for all of the possible conditions that might occur in future scenarios being modeled for Rocky Flats It is possible, however, to develop a descriptive statistical model of mass concentrations To build this frequency distribution, it is first necessary to describe the events that will provide the significant influences on the mass concentrations, including their frequency of occurrence Environmental conditions and events that influence mass loading are described above

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In order to build a distribution of mass loading, a starting value must be chosen For these calculations, the median state PM-10 value of 20 3 μg/m^3 was chosen as a representative value for conditions that might occur under future site conditions The median site-specific value of 11 6 μg/m^3 was adjusted to account for gardening and recreational horseback riding The median value would be increased by about a factor of two under these several conditions, confirming the choice of the statewide median as a reasonable starting point

Describing them again here, related to some frequency of occurrence, we present the following model Normal conditions, without significant drought and wildfire effects prevail With some regular frequency, these normal conditions are modified by the occurrence of periods with deficient rainfall, causing an increase in airborne dust In addition these normal events may be influenced by occasional wildfire events For the purpose of developing the model, the periods with deficient rainfall were assumed to occur about 25% of the time, with an increase in air concentration of about 14% Fire events were assumed to occur about 10% of the time, with increases in air concentrations of between 151% and 374%, divided equally between spring events (representing fast recovery periods) and fall events (representing slow recovery periods)

Regarding conditions that could mitigate some of these effects, it might be argued that a wildfire would not occur in an area that contained a cultivated garden The working group could not eliminate such an event, considering that the wildfire might consume the vegetation adjacent to the garden plot, but not burn the plot itself, due to irrigation Likewise, the presence of a cultivated garden would not effectively mitigate the dust-laden effects of a period of low rainfall The environmental conditions that characterize the resulting mass loading are summarized in Table A-30

Table A-30. Frequency and weighting associated with each annual environmental condition

Fire	Frequency	Weighting
No fire, normal precipitation	0 75	1
No fire, dry conditions	0 25	1 14
Spring fire, normal precipitation	0 75 x 0 05 = 0 0375	2 51
Spring fire, dry conditions	0 25 x 0 05 = 0 0125	2 87
Fall fire, normal precipitation	0 0375	4 74
Fall fire, dry conditions	0 0125	5 42

A.1.9.3 CALCULATED DISTRIBUTION – MASS LOADING FOR INHALATION

Table A-32 summarizes the calculations that result from combining these weightings with the median PM-10 mass concentration derived from the statewide air quality data contained in the Aerometric Information Retrieval System (AIRS) (U S EPA, 2001) database

Table A-31. Methodology for deriving the mass loading distribution

Fire	Weight	Fre-quency	Precip-itation	Weight	Fre-quency	Grand Weight	Grand Frequency	Mass Loading	Cumulative Frequency
None	1 0	0 9	Normal	1 0	0 75	1 0	0 6750	20 2	0 338
None	1 0	0 9	Dry	1 14	0 25	1 14	0 2250	23 1	0 788
Spring	2 51	0 05	Normal	1 0	0 75	2 51	0 0375	50 7	0 919
Spring	2 51	0 05	Dry	1 14	0 25	2 87	0 0125	58 0	0 944
Fall	4 74	0 05	Normal	1 0	0 75	4 74	0 0375	95 7	0 969
Fall	4 74	0 05	Dry	1 14	0 25	5 42	0 0125	109 5	0 994

Note A 95th percentile value of 67 μg/m^3 was established for use in RESRAD by interpolating between the 94 4th and 96 9th percentile cumulative frequency values, from the above table

These six mass loading values provide a set of input values for the "continuous linear" distribution input capability of RESRAD RESRAD requires that the minimum and maximum values (i e , 0th and 100th percentiles) be input along with these intermediately distributed values The minimum mass loading was chosen to be 9 4 μg/m^3, consistent with the lowest annual average PM-10 value observed in the samplers around the site The maximum mass loading was chosen to be 200 μg/m^3 based on the highest value observed in the statewide data, increased by a factor of about four, midway between the values that would be obtained from spring or fall fire scenarios, was chosen The same input values were used for the EPA Standard Risk Methodology calculations after passing them through a fitting routine to generate an equivalent mathematically formulated distribution

A.1.9.4 MASS LOADING FOR FOLIAR DEPOSITION

In addition to the mass loading for inhalation, the mass loading associated with deposition of contaminated dust onto garden fruits and vegetables must also be calculated As noted earlier, the radioactivity of total suspended particulate matter is about 2 5 times the radioactivity of the finer less-than 10-μm fraction The mass loading for foliar deposition can be simply derived by multiplying each mass concentration given in Table A-31 by this constant factor The 0th and 100th percentile values are calculated the same way By interpolation, a 95th percentile value of 167 5 μg/m^3 was selected as a point estimate

A.1.9.5 DIFFERENCES BETWEEN EPA STANDARD RISK METHODOLOGY AND RESRAD REGARDING CALCULATION OF CONTAMINATED FRACTION OF INHALED PARTICULATE MATTER (CONTAMINATED MASS LOADING)

RESRAD 6 0 uses the mass-loading variable to calculate inhalation dose and risk This input is multiplied by a quantity called the "Area Factor" that takes into account the amount of uncontaminated particulate matter in the air originating from outside the area of contamination The area factor is sensitive to both the area of contamination and the wind speed, increasing in magnitude with increasing area, and decreasing with increasing wind speed Figure A-12 shows

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the behavior of the Area Factor as a function of contaminated area, for a 5 m/s wind speed, similar to the annual average wind speed for Rocky Flats

EPA Standard Risk Methodology uses a constant mass loading in its calculations of inhalation risk, assuming all of the airborne particulate matter is contaminated If the RESRAD and EPA Standard Risk Methodology calculations of contaminated mass loading are compared, the RESRAD input will be reduced relative to the EPA Standard Risk Methodology input by the Area Factor multiplier In other words, for the 300-acre area considered in the scenarios being reported in this document, the contaminated mass loading is about 37% of the contaminated mass loading used in EPA Standard Risk Methodology

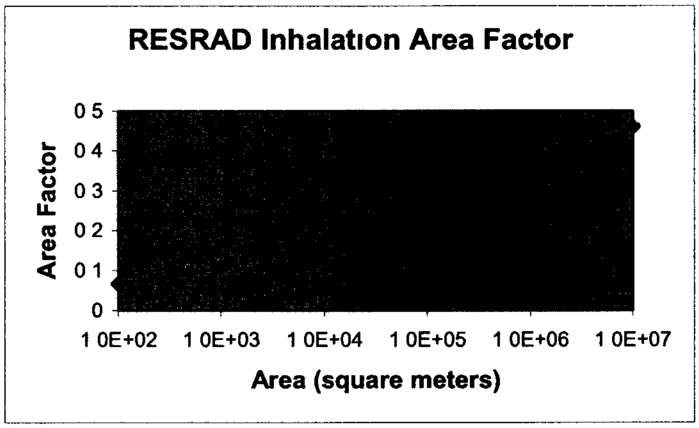

Figure A-12 Area Factor used to calculate the contaminated mass loading due to the presence of uncontaminated dust

Another difference between the conceptual approaches used in RESRAD and the Standard Risk equations concerns the interpretation of the averaging time For RESRAD, the basic exposure time is a one-year period, so all of the exposure variables are expressed as averages over one year For the Standard Risk equation, exposures are expressed as an average daily event over the entire exposure duration, typically multiple years for each scenario The mass loading term is estimated from the probability of a fire occurring over a 1-year period When the probability distribution for mass loading is applied in a Monte Carlo simulation, each iteration in RESRAD represents a 1-year average, so some values will reflect conditions when a fire occurred Over multiple years, it is unlikely that the same conditions would occur each consecutive year of exposure, the long-term average conditions are weighted towards the non-fire conditions Therefore, the use of the distribution based on 1-year average to estimate conditions over longer time periods is likely to overestimate the probability of fire conditions, and yield to higher (i e , more conservative) estimates of mass loading The working group decided not to modify the Standard Risk model to accommodate the difference in conceptual approaches

A.1.10 INHALATION RATE (IR_AIR)

Inhalation rate refers to the volume of air that is inhaled over a period of time Studies of human inhalation rates have demonstrated variability associated with age, gender, weight, health status, and activity patterns (i e , resting, walking, jogging, etc) Although an individual's inhalation

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rate will vary day-to-day and week-to-week, inhalation rates used in risk assessment generally describe an average daily rate (m^3/day) over a long period of time (i e , the exposure duration) If acute exposures associated with moderate to heavy activities may be of concern, estimates of average hourly inhalation (m^3/hour) would generally be preferred over daily averages Average daily or hourly inhalation rates will vary between people, and it is this interindividual variability that is characterized by a probability distribution for this analysis Short-term measurements, referred to as "minute volumes" (L/min), form the basis for long-term average ingestion rates The literature on inhalation rates is fairly robust, and can be loosely grouped into two categories based on study methodology (1) direct measurements using a spirometer, or (2) indirect measurements based on correlations with heart rate, energy requirements, and/or other physiological factors Data from the *Exposure Factors Handbook* (U S EPA, 1997), and a subsequent publication by Allan and Richardson (1998) on 24-hour inhalation rates formed the basis for the estimates described below

A.1.10.1 PROBABILITY DISTRIBUTION

The following probability distribution was developed for use in probabilistic risk and RSAL calculations for the Rural Resident land use scenario

- **IR_air_child ~ Lognormal (9.3, 2.9) m^3/day**
- **IR_air_adult ~ Lognormal (16.2, 3.9) m^3/day**

For the RESRAD model, the same distribution can be used by converting the units from (m^3/day) to (m^3/yr)

- mean, child 9 3 m^3/day x 365 day/yr = 3,394 5 m^3/yr
- SD, child 2 9 m^3/day x 365 day/yr = 1,058 5 m^3/yr
- mean, adult 16 2 m^3/day x 365 day/yr = 5,913 m^3/yr
- SD, adult 3 9 m^3/day x 365 day/yr = 1,423 5 m^3/yr

In RESRAD, the lognormal distribution can be specific by the mean and standard deviation of the log-transformed parameters The arithmetic and standard deviation were converted to corresponding geometric mean (GM) and geometric standard deviation (GSD) parameters Note that there are at least three conventions for specifying parameters of the 2-parameter lognormal distribution

- X ~ lognormal (arithmetic mean, standard deviation)
- X ~ lognormal (GM, GSD)
- X ~ lognormal (ln(GM), ln(GSD))

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The natural logarithm of the GM and GSD is equivalent to the arithmetic mean and standard deviation of the log-transformed parameters given above The Standard Risk approach uses the first convention, whereas RESRAD model inputs are based on the third convention Therefore, applying the same assumptions as the Standard Risk equations along with the conversion to "log space", the equivalent distribution for the rural resident for use in RESRAD is

- **IR_air_child ~ Lognormal-N (8.084, 0.305) m^3/yr**
- **IR_air_adult ~ Lognormal-N (8.657, 0 237) m^3/yr**

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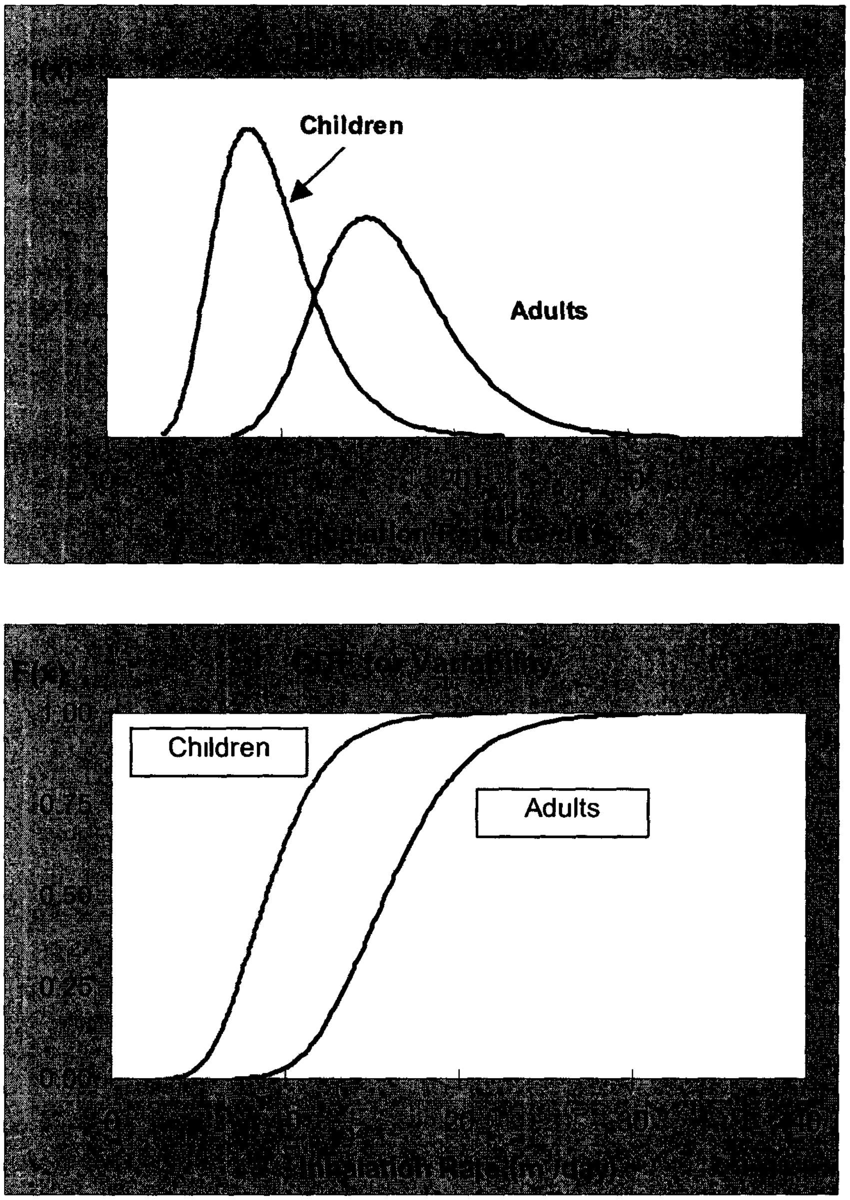

Figure A-13 Probability density function and cumulative distribution function views of the probability distribution for child and adult inhalation rate (m^3/day)

A.1.10.2 UNCERTAINTIES IN THE PROBABILITY DISTRIBUTION

The *Exposure Factors Handbook* (U S EPA, 1997) provides a comprehensive summary of the available data on inhalation rates In addition, EPA's Office of Research and Development (ORD) recently presented recommendations for probability distributions for inhalation rates (U S EPA, 2000)

Table A-32 summarizes selected data available from some key studies on inhalation rates Variability in inhalation rates at most activity levels are generally positively skewed, with more minute volumes nearer the lower end of the reported ranges (Allan and Richardson, 1998) Since inhalation is a non-negative quantity, the literature tends to report lognormal distributions fit to the available data Allan and Richardson provide graphical summaries of the fits, but no description of goodness-of-fit test statistics Adult males tend to exhibit the highest inhalation rates, with an average of approximately 17 5 m^3/day More importantly, there is remarkable consistency in estimates for both children and adults

- Estimates of average inhalation rates among toddlers and young children exhibit a range of approximately 1 m^3/day (a minimum of approximately 8 7 m^3/day to a maximum of 9 7 m^3/day)
- Estimates of average inhalation rates among adults exhibit a range of approximately 6 m^3/day (11 3–17 5 m^3/day)
- Within study groups, the interindividual variability is very low, as shown by coefficients of variation (ratio of SD to the mean) of approximately 0 25

For children (males/females combined, ages 7 months to 4 years) the available data fit a lognormal distribution with parameters (AM, SD) of [9 25, 2 9] m^3/day, where the standard deviation reflects the highest of the values reported among study populations of children (i e , Layton et al , 1993) For adults (males/females combined, ages 20-59), the available data also fit a lognormal distribution [16 2, 3 86] m^3/day These results (see Table A-33) are within the range of all reported values, as well as the values recommended by EPA for risk assessment in the *Exposure Factors Handbook* (U S EPA, 1997)

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Table A-32. Summary of recommended values for inhalation rates (*Exposure Factors Handbook*, U S EPA, 1997, Table 5-23)

Age Group	**Inhalation Rate**	
	Long-term Exposure (m^3/day)	**Short-term Exposure (m^3/hr)**
Child, 1 to 2 years	6 8	rest - 0 3 sedentary - 0 4 light activity - 1 0 moderate activity - 1 6 heavy activity - 1 9
Child, 3 to 5 years	8 3	
Child, 6 to 8 years	10 0	
Adult, 19+ years	11 3 - 15 2	rest - 0 4 sedentary - 0 5 light activity - 1 0 moderate activity - 1 6 heavy activity - 1 9
Adult Worker	not reported	hourly average - 1 3 hourly average, high-end - 3 3 slow activities - 1 1 moderate activities - 1 5 heavy activities - 2 5

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Table A-33. Summary of point estimates and probability distribution parameters for inhalation rates

Point Estimate - U.S. EPA Exposure Factors Handbook (1989)			
Population	CTE, RME	Units	Comments
Children, M/F	8 7, --	m³/day	Long-term exposures for children 1-12 years
Adults, male	15 2, --	m³/day	Long-term exposures for adult males
Adults, female	11 3, --	m³/day	Long-term exposures for adult females
Outdoor worker	1 3, 3 5	m³/hr	Short-term exposures for outdoor workers, hourly average
Lognormal Probability Distribution - U.S. EPA Exposure Factors Handbook (1989)			
Population	Lognormal Distribution (m³/day)		Comments
	arithmetic mean	standard deviation	
Children, male	9 3	2 85	Based on Layton (1993) study in which inhalation rates were based on BMR and energy expenditures, children aged 3-10 years
Children, female	8 65	2 65	Children aged 3-10 years
Adults, male	16 75	5 32	Adults aged 18-30 years
Adults, female	11 14	5 37	Adults aged 18-30 years
Lognormal Probability Distribution - based on Allen and Richardson (1998)			
Population	arithmetic mean	standard deviation	Comments
Children, male	9 67	2 67	Study of Canadian subjects using time-activity patterns and minute volumes from USA studies, values represent 24-hr inhalation rates, male children 7 months to 4 years of age
Children, female	8 81	2 37	Female children 7 months to 4 years of age
Children M/F	9 25	2 57	M/F children 7 months to 4 years of age
Adults, male	17 54	4 06	Male adults 20 to 59 years of age
Adults female	14 89	3 13	Female adults 20 to 59 years of age
Adults, M/F	16 2	3 86	M/F adults 20 to 59 years of age

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Table A-34 Confidence ratings for Inhalation Rate (IR_air) for Rural Resident scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Studies are from peer reviewed journal articles and an EPA peer reviewed report. Key study was published subsequent to the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Accessibility	All information is from EPA or peer reviewed literature	High
• Reproducibility	Individual-level data from questionnaires and interviews are unavailable	Medium
• Focus on factor of interest	Studies focused on age-specific ventilation rates and factors influencing them. Goal of key study was to generate probability distributions for use in Monte Carlo simulation	High
• Representativeness of study population	Six age groups of Canadians were studied to obtain 24-hour inhalation rates. Time activity pattern information is based on U S populations so the study results are considered representative	High
• Primary data	According to *Exposure Factors Handbook* (U S EPA, 1997), most studies involved data collection or reanalysis of existing data	Medium
• Currency	Recent studies were evaluated	High
• Adequacy of data collection period	Insufficient information presented to assess the data collection period. Numerous studies were reviewed and summarized to derive probability distribution in the key study	Medium
• Validity of approach	Studies evaluated in the key study used a combination of direct and indirect measurements. Concept of combining minute volume with time activity patterns is appropriate	Medium
• Study size	Study group size not specified, but results from numerous studies were incorporated into statistics of key study	Medium
• Characterization of variability	Mean and SD are provided, along with a description of right skew. Lognormal distribution is a convenient choice for non-negative, right-skewed distribution, but goodness-of-fit and graphical evaluations of fit were not described	Medium
• Lack of bias in study design	Subjects were selected at random for some studies	High
• Measurement error	Interindividual variability within study subjects is relatively small. No indication of bias in study designs	High
Other Elements		
• Number of studies	Numerous minute volume data sources were compiled to derive estimates of summary statistics	High
• Agreement between researchers	There is general agreement in estimates by age group among the different studies	High
Overall Confidence Rating	Studies group inhalation rates by appropriate factors of age, gender, and activity. Minute volumes reflect Canadian subjects, whereas activity pattern data is from U S subjects. Consistently low coefficient of variation within studies	High

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A.1.11 EXPOSURE FREQUENCY

Exposure frequency refers to the number of days per year that a resident is present at home, rather than at work or on vacation Given that the toxicity endpoint is a long-term average exposure (the endpoint of concern is cancer), this input variable will represent a long-term average time at the residence For the Rural Resident land use scenario, it is assumed that if an individual is at home, they may be exposed via one or more exposure pathways for 24-hours per day For this analysis, no distinction is made between exposure frequencies for men and women, or for children and adults The maximum number of days per year is 365 days

The *Exposure Factors Handbook* (U S EPA, 1997) summarizes survey data on population mobility for the U S population The sample sizes for the major studies are very large (*n* greater than 1,000), reflecting national surveys The difficulty in estimating population activity patterns and mobility from a survey is that it represents a snapshot in time, and there is uncertainty in determining the total duration that an individual will reside at the same house (see Section A 1 12) Extrapolations to long time periods are required since personal diaries cover short periods of time However, there is less uncertainty associated with estimating the days per year that an individual spends time at home

The Superfund default CTE for residential exposure frequency is 234 days/yr, which corresponds to the fraction of time spent at home (64%) for both men and women based on a study of time use patterns summarized in 1990 In other words, the available data suggest that, on average, individuals spend approximately two-thirds of the year at home

A.1.11.1 PROBABILITY DISTRIBUTION OF EXPOSURE FREQUENCY

For this analysis, a probability distribution was generated from the CTE given by the *Exposure Factors Handbook* (U S EPA, 1997) (234 days/yr) and professional judgment regarding a plausible range among a residential population The maximum value of 350 days was selected to reflect an average of approximately two weeks per year spent away from home, either on family vacation or business travel A minimum of 175 days/yr was selected to reflect a minimum of approximately 50% of the year spent at home

Given reliable information regarding the central tendency, and plausible estimate for the minimum and maximum, the following triangular distribution was selected to represent variability in exposure frequency among rural residential populations

EF ~ Triangular (175, 234, 350) days/yr

The parameters for the triangular distribution are as follows

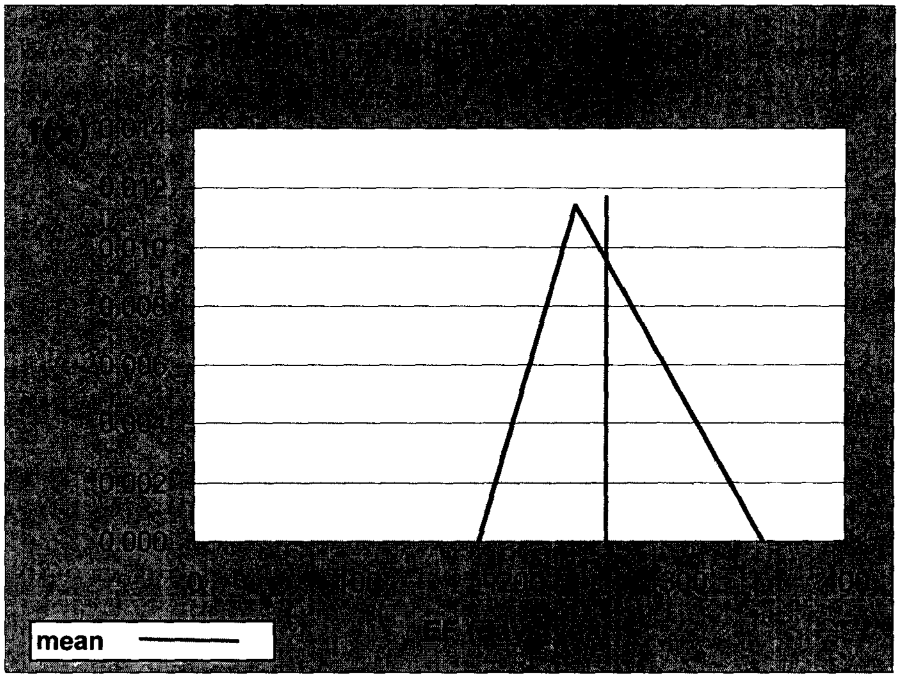
- minimum 175 days/yr
- mode 234 days/yr
- maximum 350 days/yr

The mode characterizes the "most likely" value and will equal the mean for distributions that are symmetrical Figure A-14 presents the probability density and cumulative distribution views for these distributions The mean, 90th, 95th and 99th percentiles are 253, 305, 318, and 336 days/yr

A.1.11.2 UNCERTAINTIES IN THE EXPOSURE FREQUENCY PROBABILITY DISTRIBUTION

The triangular distribution is a reasonable approximation for the "true" distribution for exposure frequency given that the variable is truncated at the high-end by definition (i e , 350 days per year) It may be possible to obtain the original survey data results that formed the basis for the CTE recommended by EPA for use in Superfund risk assessments However, it is expected that use of an alternative right-skewed (and truncated) distribution would yield very similar percentile estimates, and would therefore have only a minor effect on the risk estimates

Use of 350 days/yr as a high-end truncation limit is viewed as a reasonably conservative estimate of exposure frequency in the absence of site-specific data



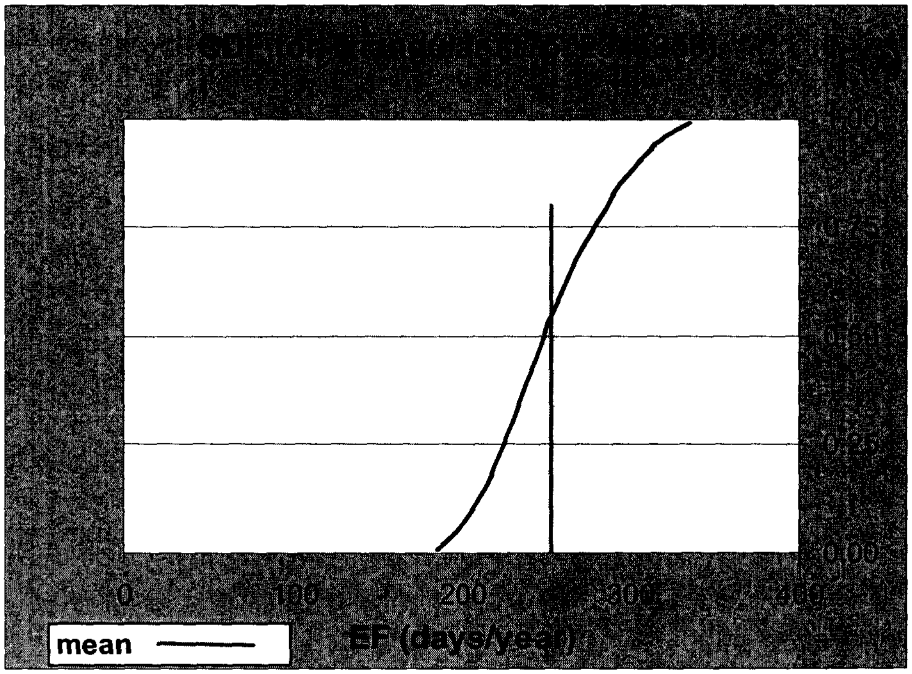


Figure A-14 Probability density function and cumulative distribution function views of the triangular distribution for exposure frequency (days/yr) for the rural resident

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Table A-35 Confidence ratings for exposure frequency for Rural Resident scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Relevant analyses of census data in one major study are in the peer review literature and in the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Accessibility	See above	High
• Reproducibility	Results may differ as activity patterns change over time, data are from national survey in 1985 Information on questionnaires and interviews were not provided	Medium
• Focus on factor of interest	Activity patterns were ascribed to indoor or outdoor locations Summary data specifies time spent at home	High
• Representativeness of study population	Study is based on survey data of the U S population in 1985, both male and female Time spent at home may have changed during the past 15 years No indication of fraction of respondents that live in rural vs urban settings	High
• Primary data	One study analyzed activity patterns using a national survey	High
• Currency	Study was published in 1991(based on data from 1985)	Medium
• Adequacy of data collection period	Data were collected Jan to Dec 1985 Respondents described activities for a one-day period	High
• Validity of approach	Approach is based on questionnaires and interviews Responses are based on diaries and mail back surveys	High
• Study size	Study group size not specified, but collectively the references on activity patterns summarized by the *Exposure Factors Handbook* had sample sizes of 922 to 5,000	High
• Characterization of variability	Data reported as the average time spent at home, without an estimate of variability 234 days per year is EPA's standard default CTE based on 1996 draft of *Exposure Factors Handbook*, which reports 64% of time, was spent at home The current 1997 draft of *Exposure Factors Handbook* reports essentially the same value 66% of time (954 of 1,440 minutes) Min and max are uncertain, prompting the use of a triangular distribution Uncertainty in defining the mode of the triangle based on the AM given by the data	Low
• Lack of bias in study design	Activities reported in 1985 may differ from current activities	Medium
• Measurement error	Potential error associated with diary entries and 24-hour recall	Medium
Other Elements		
• Number of studies	One, but sample size is large	Medium
• Agreement between researchers	Analysis was the basis for the default CTE point estimate used by EPA However, no information is available on agreement with choice of probability distribution	Medium

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Considerations	Rationale	Rating
Overall Confidence Rating	Large sample size, survey responses focus directly on time spent at home Uncertainty associated with characterization of variability, potential change in activity patterns since 1985, and potential error associated with 24-hour recall	Medium

A.1.12 EXPOSURE DURATION

Exposure duration refers to the number of years that a resident is present at the same residence This variable applies only to the standard risk equation modeling (RESRAD is used to calculate only annual dose in this task) For the Rural Resident land use scenario, both children and adults comprise the population of concern, and exposure is assumed to begin at birth Census data provide representations of a cross-section of the population at specific points in time, but the surveys are not designed to follow individual families through time (U S EPA, 1997) The *Exposure Factors Handbook* (U S EPA, 1997) summarizes the key studies on population mobility These studies use a variety of methods to estimate residential tenures, including (1) calculate the average current and total residence times, (2) model current residence time, and (3) estimate the residential occupancy period Each of the key studies and methodologies provides similar estimates as summarized in Table A-36

Table A-36 Summary of key studies for residential exposure duration, based on U S EPA (1997), Table 15-174

Study	Summary Statistics (years)	Methodology
Isreali and Nelson, 1992	mean = 4 6 1/6 of a lifetime of 70 years, or 11 7 years	Average current and total residence times
US Bureau of the Census, 1993	50^{th} percentile = 9 years 90^{th} percentile = 33 years	Current residence time
Johnson and Capel, 1992	mean = 12 years 90^{th} percentile = 26 years 95^{th} percentile = 33 years 99^{th} percentile = 47 years	Residential occupancy period

A 1.12.1 PROBABILITY DISTRIBUTION FOR EXPOSURE DURATION

For this analysis, a probability distribution was generated from the empirical distribution function reported by Johnson and Capel (1992) for n = 500,000 simulated individuals (both male and female) given in Table A-37

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Table A-37 ECDF for residential occupancy period reported by Johnson and Capel (1992), based on EPA (1998), Table 15-167

Percentile[1]	Years	Percentile	Years
0.05	2	0.95	33
0.10	2	0.98	41
0.25	3	0.99	47
0.50	9	0.995	51
0.75	16	0.998	55
0.90	26	0.999	59

[1]maximum observed value was 87 years

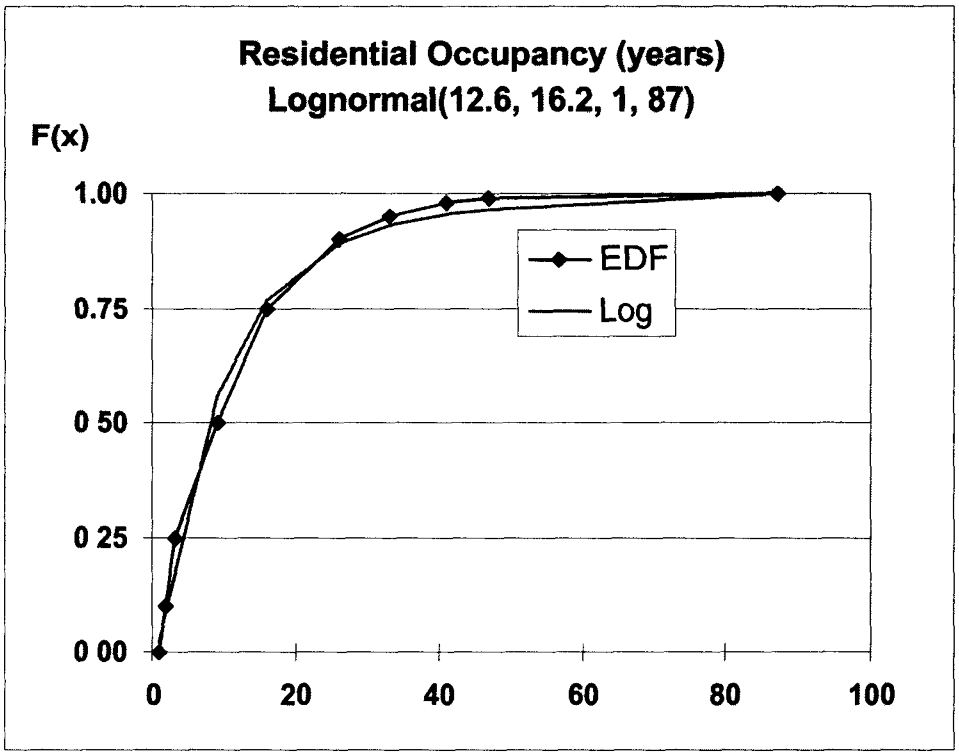

Figure A-15. Comparison of empirical distribution function and truncated lognormal distribution for residential occupancy period (exposure duration, years)

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These data were fit to a lognormal distribution using least squares regression to estimate the AM of 12 6 years and SD of 16 2 years Figure A-15 gives a comparison of the empirical distribution function to the fitted lognormal distribution Truncation limits of 1 and 87 years are based on professional judgment that the maximum observed values are plausible bounds given the large sample size of the survey The corresponding probability distribution function is shown in Figure A-16

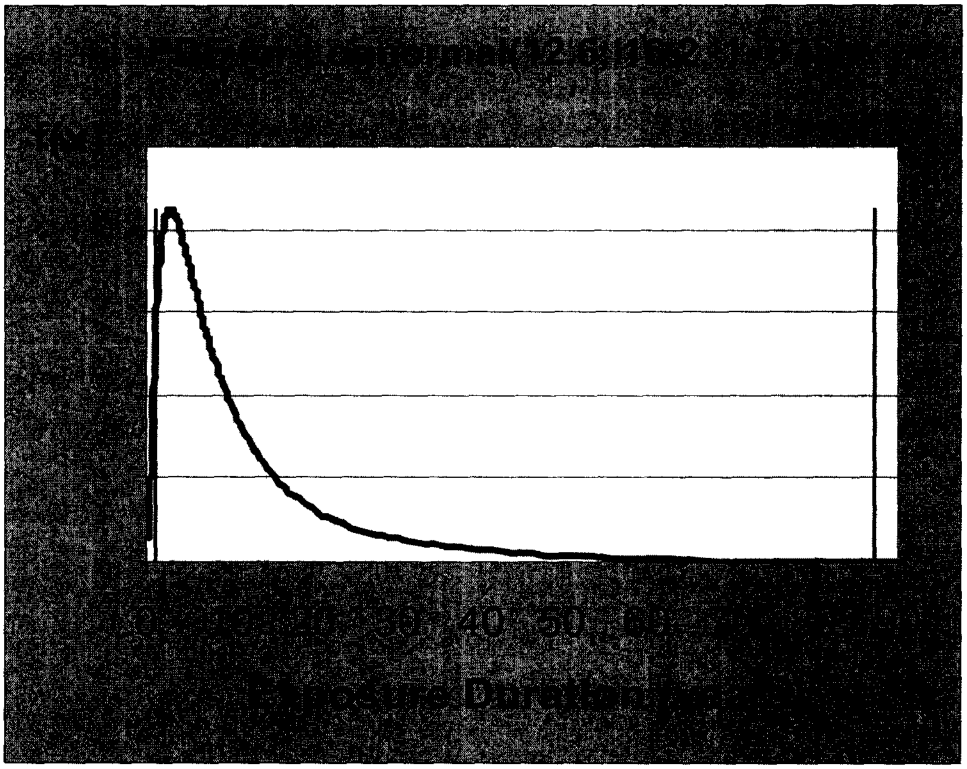

Figure A-16. Probability density function for the lognormal distribution for exposure duration (years) for the rural resident The cumulative distribution function is shown fit to empirical data in Figure A-15

Given reliable fit to the empirical distribution function the following lognormal distribution was selected to represent variability in exposure duration among rural residential populations

ED ~ Truncated Lognormal (12.6, 16.2, 1, 87) years

The parameters for the truncated lognormal distribution are as follows

• arithmetic mean	12 6	years
• arithmetic standard deviation	16 2	years
• minimum	1	year
• maximum	87	years

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This use of truncation limits on this distribution does have a moderate effect on the parameter estimates used in the Monte Carlo simulation The maximum value of 87 years truncates the distribution at the 99 3rd percentile, while the minimum value of 1 year truncates the distribution at the 1 9th percentile These truncation limits have the combined effect of reducing the mean to 12 0 years (4 8%) and reducing the SD to 12 3 years (24 1%) This change reflects the relatively high coefficient of variation for this distribution (CV = SD/mean = 1 3), however, the maximum of 87 years is considered to be a reasonable approximation of an individual who lives at the same residence their entire life The 50th, 90th, 95th and 99th percentiles of this distribution are 7 7, 27 4, 39 3, and 77 0 years

A.1 12 2 UNCERTAINTIES IN THE EXPOSURE DURATION PROBABILITY DISTRIBUTION

There is relatively high confidence in the data set and probability distribution used to characterize variability in residential exposure duration The standard RME point estimate for use in Superfund risk assessments (for cancer) is 30 years, which is approximately the 91st percentile of this distribution

Table A-38 Confidence ratings for exposure duration for Rural Resident scenario

Considerations	Rationale	**Rating**
Study Elements		
• Level of peer review	U S Bureau of Census, U S EPA, and National Center for Health Statistics review of National Survey Data Relevant analyses of census data in three major studies are in the peer review literature Johnson and Capel study published in 1992 was selected as the basis for the distribution	High
• Accessibility	Papers are available from peer review journals and are evaluated in the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Reproducibility	According to *Exposure Factors Handbook* (U S EPA, 1997), results can be reproduced or methodology can be followed and evaluated	High
• Focus on factor of interest	Census data provide information on relevant cross-section of population at specific points in time, but surveys are not designed to follow families through time Uncertainty in measurement of current residence in house vs total residential occupancy period (ROP) until moving or dying	Medium
• Representativeness of study population	See above Studies are based on survey data of the U S population	High
• Primary data	Two studies are based on modeled data and one is based on interviews	Medium
• Currency	Reports were published in 1992 (based on data from 1985 and 1987), 1993 (based on data from 1993 and 1994 {projected})	Medium
• Adequacy of data collection period	Other than the years of the survey, details regarding the data collection methodology are not provided	Medium
• Validity of approach	Data do not account for each member of household Uncertainty in total residential occupancy period (ROP)	Medium

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Considerations	Rationale	Rating
	because Census data indicate years in residence and probability of not moving each year based on demographics Johnson and Capel (1992) use Monte Carlo analysis to simulate ROP based on Census data (current residence time, mobility), and vital health statistics data (mortality)	
• Study size	National surveys ranging from 15,000 to 500,000	High
• Characterization of variability	Lognormal distribution provides reasonable fit to 12 percentile statistics of empirical distribution function using least squares regression Truncation limits of 1 year and 87 years represent the 1 9th and 99 3rd percentiles, respectively Given the high variance of the distribution, the truncation reduces the parameters (mean, SD) from (12 6, 16 2) years to (12 0, 12 3) years Consistency across three studies increases confidence in central tendency and high-end percentiles	High
• Lack of bias in study design	Census data from a study by Israeli and Nelson (1992) (see *Exposure Factors Handbook,* U S EPA, 1997, Tables 15-163 and 15-164) suggest that individuals in the region most relevant to Rocky Flats (West) have the lowest average total residence time Therefore, using national instead of regional data may tend to overestimate occupancy period	Medium
• Measurement error	None reported	High
Other Elements		
• Number of studies	Three studies are recommended by the *Exposure Factors Handbook* (U S EPA, 1997)	High
• Agreement between researchers	The studies produce very similar results	High
Overall Confidence Rating	Large sample size and good concurrence among different study methodologies Uncertainty in combining mobility and mortality data to simulate total residence time, potential bias in national rather than regional data Lognormal distribution gives reasonable approximation to empirical distribution function, but truncation limit constrains the variance of the distribution by 25%	Medium

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A.2.0 EXPOSURE VARIABLES FOR THE WILDLIFE REFUGE WORKER SCENARIO

For the Wildlife Refuge Worker scenario, five exposure variables were described by probability distributions in the probabilistic modeling (see Table A-39) For inhalation rate, exposure frequency, and exposure duration, the distributions are uniquely applicable to the wildlife refuge workers For mass loading and adult soil ingestion, the distributions are applicable to both rural residents (Section A 1) and wildlife refuge workers

Table A-39. Variables described by a probability distribution in the Wildlife Refuge Worker scenario

• Inhalation Rate	• Mass Loading
• Exposure Frequency	• Adult Soil Ingestion
• Exposure Duration	

A.2.1 INHALATION RATE (IR_AIR)

Inhalation rates for workers will vary greatly, depending on the time spent at different levels of activity While inhalation may be expressed as an average daily rate (by averaging over an eight-hour workday), the basic unit of interest is the short-term average rate (e g , minutes or hours) The Rocky Mountain Arsenal risk assessment (Ebasco, 1994) provides estimates of inhalation for biological workers based on a calculation of the time-weighted average breathing rates (see Section B 3 4 1 4) These estimates form the basis for the probability distributions used in this analysis

A.2.1.1 PROBABILITY DISTRIBUTION FOR INHALATION RATE

The following probability distribution was developed for use in the probabilistic approach using Standard Risk equations and RESRAD calculations for the Wildlife Refuge worker scenario

IR_air_wildlife ~ min + (max - min) x Beta (a, b) m^3/hr

The beta distributions are defined by four parameters

- shape parameter a 1 79 unitless
- shape parameter b 3 06 unitless
- minimum 1 1 m^3/hr
- maximum 2 0 m^3/hr

For RESRAD, the beta distribution was rescaled to units of m^3/yr, rather than m^3/hr Therefore, the minimum and maximum (not the shape parameters) were calculated as follows

- minimum = 1 1 m^3/hr x 24 hrs/day x 365 days/yr = 9,636 m^3/yr
- maximum = 2 0 m^3/hr x 24 hrs/day x 365 days/yr = 17,520 m^3/yr

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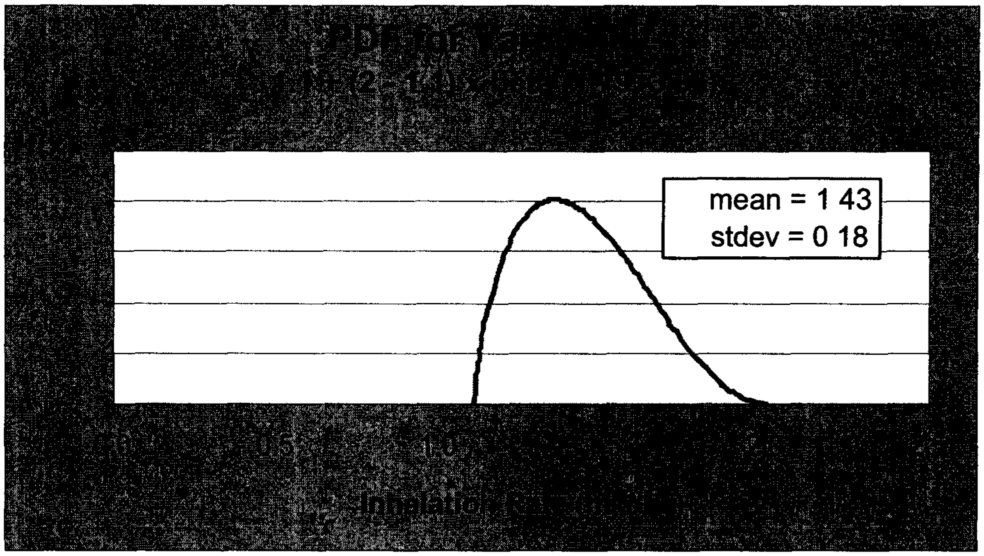

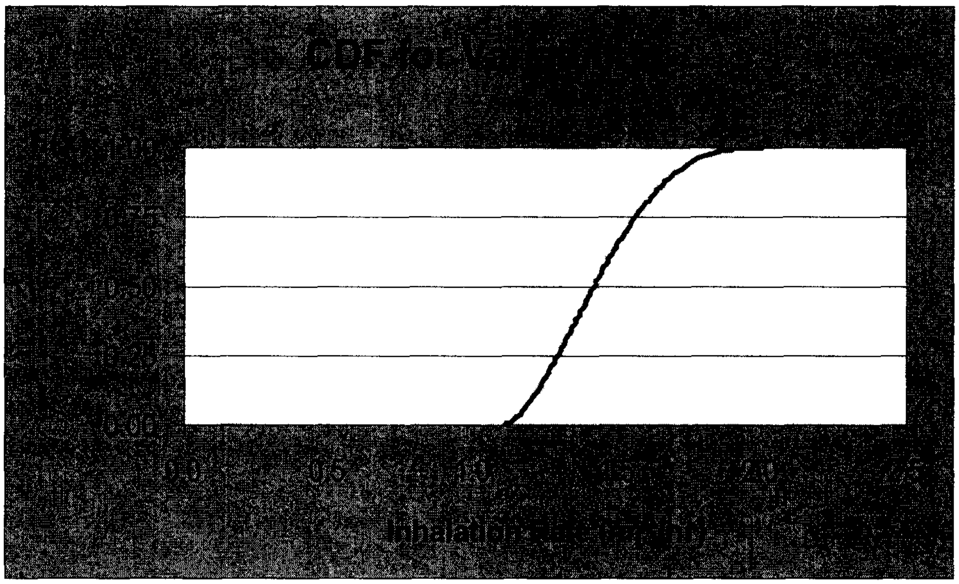

Figure A-17 Probability density function and cumulative distribution function views of the probability distribution for wildlife refuge worker inhalation rate (m³/hr)

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A.2.1.2 UNCERTAINTIES IN THE INHALATION RATE PROBABILITY DISTRIBUTION

The Rocky Mountain Arsenal report (Ebasco,1994) describes the methodology used to generate the estimates of the time-weighted average breathing rates among biological workers A brief description is given here Activity patterns were divided into three categories based on the extent of contact with site soils

P1 (indoor), P2 (middle), and P3 (higher)

Survey data on activity patterns among biological workers were used to develop a discrete probability distribution for the amount of time engaged in each category In addition, three categories of breathing rates were specified

BR (lower = 0 66), BR (middle = 2 0), and BR (heavy = 3 8)

The time-weighted average was calculated based on the following equation

$$TWA = (P_{lower})(BR_{lower}) + (P_{middle})(BR_{middle}) + (P_{high})(BR_{high})$$

A Monte Carlo simulation was run to randomly sample from the probability distribution for ***P***, with each iteration yielding a different estimate of the time-weighted average breathing rate The summary statistics for the cumulative distribution are given below

empirical distribution function = {percentiles, values} = {0 01, 0 025, 0 05, 0 075, 0 10, 0 25, 0 50, 0 75, 0 90, 0 925, 0 95, 0 975, 0 99}, {0 72, 0 72, 0 72, 0 73, 0 73, 0 80, 1 14, 1 47, 1 96, 2 07, 2 12, 2 45, 2 45}

These data could be incorporated into a probabilistic model directly as an empirical distribution A beta distribution was fit to the summary statistics because it is both flexible in shape and defined by a minimum and maximum value The process used to generate the probability density function, as described above, will generate a plausible estimate of the minimum (100% of exposure time at lowest breathing rate) and maximum (100% of exposure time at highest breathing rate) This characteristic of the data set lends itself to a close fit to the beta distribution

Table A-40. Confidence ratings for Inhalation Rate for Wildlife Refuge Worker scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Ebasco, 1994 study of survey data on activity patterns among biological workers used to develop a discrete probability distribution for the amount of time engaged in one of three-activity levels category	Medium
• Accessibility	All information is from the Rocky Mountain Arsenal (RMA) report	High
• Reproducibility	Individual-level data from questionnaires and interviews are unavailable	Medium
• Focus on factor of interest	Study focused on survey of activity patterns of biological workers Inhalation rates are based on Exposure Factors Handbook (U S EPA, 1997)	Medium
• Representativeness of study population	Studied biological workers, which is relevant to the wildlife refuge workers	High
• Primary data	Involved data collection	High
• Currency	Recent studies were evaluated (within 10 years)	High
• Adequacy of data collection period	Insufficient information presented to assess the data collection period	Medium
• Validity of approach	Concept of combining minute volume with time activity patterns is appropriate	Medium
• Study size	Study group size not specified	Low
• Characterization of variability	Data yield a robust empirical distribution Goodness-of-fit and graphical evaluations of fit were conducted and support the use of a beta distribution	Medium
• Lack of bias in study design	Criteria for selecting subjects are unknown	High
• Measurement error	Cannot assess this element without further details regarding study protocols and analysis	Low
Other Elements		
• Number of studies	One study, although numerous supporting studies provide minute volume data for purposes of comparison	High
• Agreement between researchers	There is general agreement about the utility and representativeness of the study	High
Overall Confidence Rating	Minute volumes were not measured directly, however a site-specific study on a relevant population is preferred over surrogate studies	Medium

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A.2.1 3 NOTES ON THE BETA DISTRIBUTION

The following discussion presents basic information on the use and definition of the beta distribution, and summarizes a comparison of the distribution functions used by RESRAD 6 0 and Crystal Ball® v 4 0g Further information on these distributions can be obtained from the user's manual or help menus included with the respective software

Why use the Beta Distribution? – The beta distribution is very flexible due to its two shape parameters It can assume nearly any shape, including right skewed, left skewed, symmetric, and uniform (rectangular) Most lognormal distributions can be approximated well with a beta distribution An advantage of the beta distribution is that it is bounded by definition at both a minimum and maximum value Other distributions may require more arbitrary definitions for truncation limits This does not mean that use of the beta removes the decision making altogether As with the lognormal distribution, which is bounded at zero by definition, sometimes a higher "lower limit" is needed For example, if we describe body weight with a lognormal distribution, it would not make sense to allow for a 0 kg individual, so a truncation limit would be needed to increase the minimum value to a plausible range The same common sense applications should accompany the use of the beta distribution

Rescaling and Relocating the Beta Distribution [0, 1] – Most algorithms define the shape of the beta for values in the interval [0, 1] The distribution can then be rescaled to different units, and relocated, while still maintaining the shape The algorithms used to accomplish this rescaling and relocating can vary The easiest and most straightforward approach is to select or fit the two shape parameters for the interval [0, 1] and then adjust the scale as follows

$$beta_{[\min\ \max]} = \min + (\max - \min) \times beta_{[0\ 1]}$$

goodness-of-fit software will fit all four parameters [α_1, α_2, min, max] simultaneously A good test of these parameter estimates would be to rescale a data set so that all values lie within the interval [0, 1]—dividing by the maximum value in the data set is one approach

The beta distribution as used in RESRAD and Crystal Ball® – For the EPA standard risk methodology approach, simplify your life by removing the "scaling" parameter in Crystal Ball® (i e , set scaling parameter s = 1 0) Define the assumption cell for the variable as usual, so that it yields a value in the interval [0, 1], then include the min and max in the risk formula as shown above To convert units of variables defined in the EPA Standard Risk Methodology spreadsheet so that they match the RESRAD units, apply the conversions only to the [min, max], do not modify the shape parameters See the Example 1 below for a more visual explanation

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The RESRAD 6.0 Beta Distribution Function

$$f(x) = \frac{(P+Q-1)!(x-Min)^{P-1}(Max-x)^{Q-1}}{(P-1)!(Q-1)!(Max-Min)^{P+Q-1}}$$

where,

P	=	shape parameter (alpha 1 or α_1)
Q	=	shape parameter (alpha 2 or α_2)
Min	=	minimum
Max	=	maximum

for P > 0 and Q > 0, and Max > Min

If the generic interval [min, max] is defined as [0, 1] then the equation reduces to

$$f(x) = \frac{(P+Q-1)!(x)^{P-1}(1-x)^{Q-1}}{(P-1)!(Q-1)!}$$

and the beta random variate lies within the interval $0 < x < 1$

The Crystal Ball® Beta Distribution Function

Using the same parameter notation as RESRAD

$$f(x) = \frac{(P+Q-1)!(x/s)^{P-1}(1-x/s)^{Q-1}}{(P-1)!(Q-1)!}$$

where,

P	=	shape parameter (alpha 1 or α_1)
Q	=	shape parameter (alpha 2 or α_2)
s	=	scale parameter
Min	=	minimum
Max	=	maximum

for P > 0, Q > 0, (P + Q + 1) < 1750, Max > Min, and s > 0

This definition will yield a beta random variate that lies within the interval $0 < x < s$, as well as the interval [min, max]. Since both conditions are satisfied, if the min > 0 or max < s, this can result in a very "truncated" looking distribution. Note that Crystal Ball® yields the same equation as RESRAD if (and only if) the scale parameter, s, is set to 1.0

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Example 1. Unit Conversions and the beta distribution, X ~beta(alpha 1, alpha 2).

Assume data are collected for variable X, and fit to a beta distribution X ~ beta (2,7) with a minimum of 0.2 and maximum of 1.2. Now assume that the units for the variable are converted by multiplying by 10. A new beta distribution is fit to this data set yielding X ~ beta (2, 7), but with a new minimum of 2.0 and maximum of 12.0 (multiply previous *min* and *max* by 10). Note that the two shape parameters do not change, so the shape of the probability density function remains the same in the graphs below. Only the scale of the x-axis is modified by the change in the interval. Parameters are [alpha 1, alpha 2, min, max]

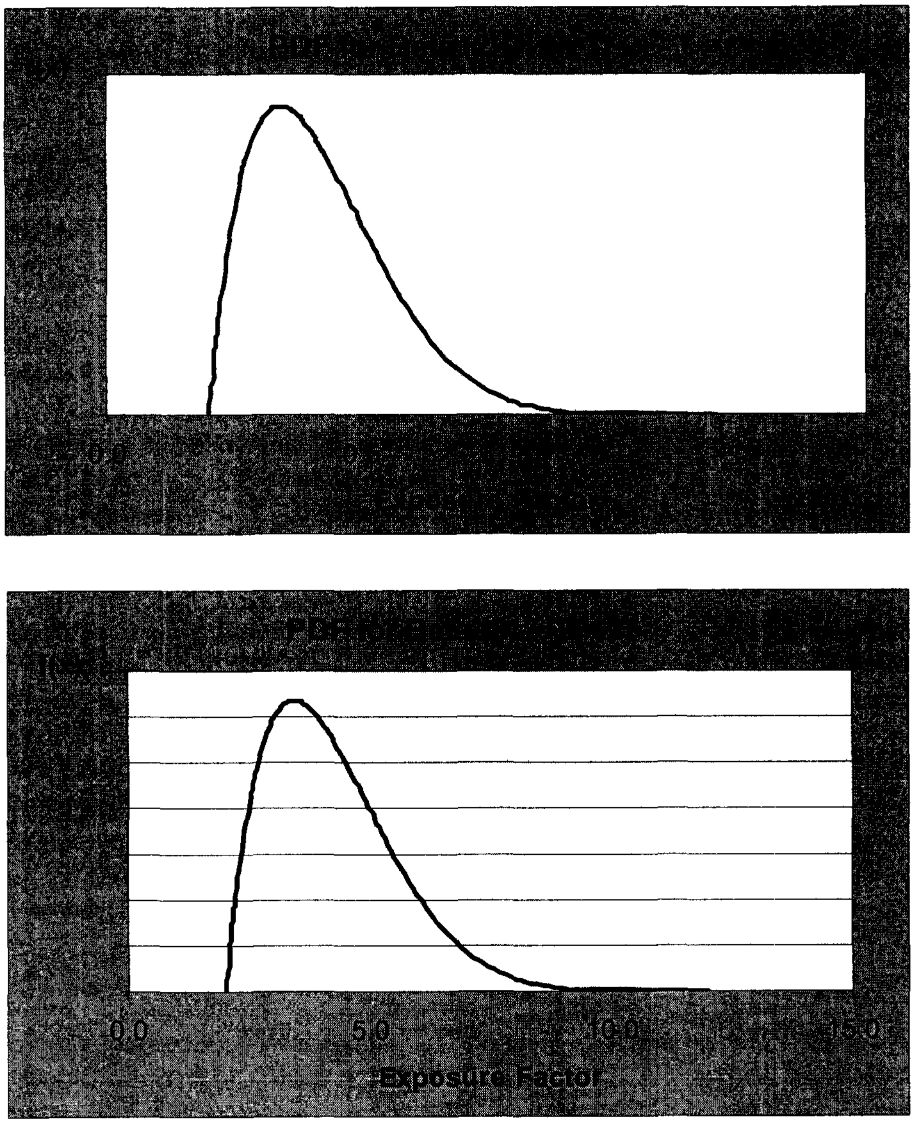

Figure A-18. Probability density functions (PDF) for the beta distribution defined by the same shape parameters, but different scaling parameters (minimum and maximum)

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A.2.2 EXPOSURE FREQUENCY

For the Wildlife Refuge Worker scenario, exposure frequency represents the average number of days per year that a refuge worker spends on site The Bureau of Labor Statistics maintains National Survey Data on occupational activity patterns The Superfund default central tendency and RME estimates for workers (both full-time and part-time) are 219 days/yr and 250 days/yr, respectively The 250 days/yr reflects an individual who works 5 days per week for 50 weeks of the year (thereby taking a single two-week vacation, for example) These estimates are based on National Survey Data of the U S population from 1991

Since it is likely that different occupations may reflect substantially different activity patterns, ideally a sub-category representative of wildlife refuge workers would be used to estimate exposure frequency Such occupation-specific information has been obtained by the U S Fish and Wildlife Service in a National Wildlife Refuge Survey, in which wildlife refuge workers were interviewed from three refuges (Crab Orchard, IL, Malheur, OR, and Minnesota Valley, MN) Additionally, data for 33 wildlife refuge workers are summarized in the Rocky Mountain Arsenal report (Ebasco, 1994) The responses allow for estimates of either hours per day or days per year While the sample size is relatively small, the estimates are similar to that of the National Survey Data, and provide a more occupation-specific data set for the exposure scenario characterized in this analysis

A.2.2.1 PROBABILITY DISTRIBUTION FOR EXPOSURE FREQUENCY

This report recommends the following probability distribution for use in risk equations that are based on EPA *Risk Assessment Guidance for Superfund* (U S EPA, 1989) in order to characterize *interindividual* variability in exposure frequency among wildlife refuge workers

EF ~ Truncated Normal (225, 10.23, 200, 250) days/yr

The truncated normal distribution is defined by four parameters

- arithmetic mean 225 days/yr
- standard deviation 10 23 days/yr
- minimum 200 days/yr
- maximum 250 days/yr

The probability distribution (PDF and cumulative distribution function) is shown in Figure A-19 Given that a normal distribution has infinite lower and upper tails, it is reasonable to truncate the distribution at plausible bounds The effect of the truncation limit is to alter the original parameter estimates (mean, SD) that are effectively used in a Monte Carlo simulation For this analysis, the coefficient of variation (CV = SD / mean) is very low (0 05), so truncating at 200 and 250 days/yr has a minimal effect These truncation limits remove 0 7% of the tail at both ends, and due to the symmetrical shape, there is no change in the mean or SD

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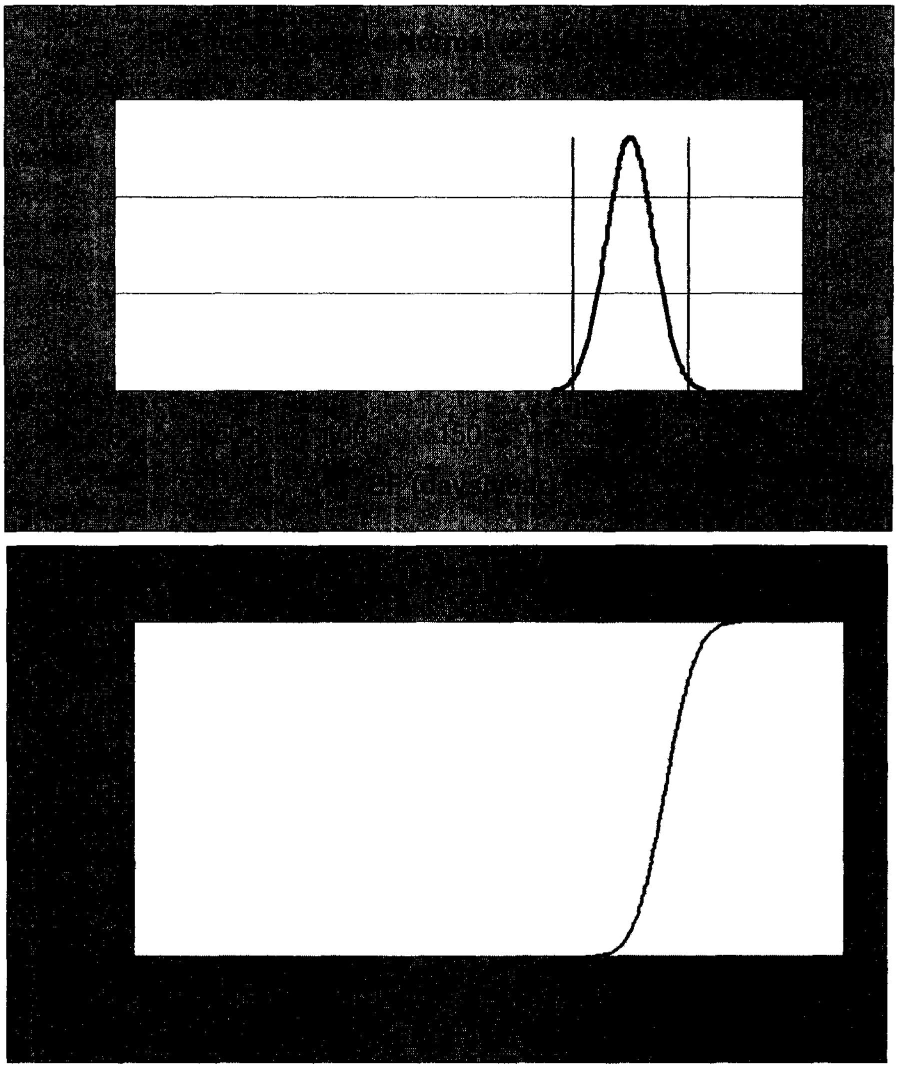

Figure A-19. Probability density function and cumulative distribution function views of the truncated normal distribution for (adult) exposure frequency (days/yr) for the wildlife refuge worker

A.2.2 2 UNCERTAINTIES IN THE EXPOSURE FREQUENCY PROBABILITY DISTRIBUTION

The use of a normal distribution is supported by the data reported in the Rocky Mountain Arsenal by U S Fish and Wildlife on wildlife refuge workers in three different locations (Ebasco, 1994) The AM (225 days/yr) is slightly greater than the CTE reported by the Bureau of Labor Statistics for all occupations (219 days/yr) The maximum value of 250 days/yr is consistent with the RME estimate recommended for use at Superfund sites, and may be viewed as a reasonable upper bound for individuals who work weekdays only, and take two weeks of vacation per year The lower bound of 200 days per year suggests that the range among different workers at the refuge is relatively narrow (i e , 50 days)

Table A-41 Confidence ratings for exposure frequency for Wildlife Refuge Worker scenario

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Data collected by U S Fish and Wildlife on wildlife refuge workers in three different locations (Ebasco, 1994) Reported in Rocky Mountain Arsenal (pp B 3-149-150) Truncation limits are professional judgment The maximum value of 250 days/yr is consistent with the RME estimate recommended for use at Superfund sites, and may be viewed as a reasonable upper bound for individuals who work weekdays only, and take two weeks of vacation per year The lower bound of 200 days per year suggests that the range among different workers at the refuge is relatively narrow (i e , 50 days)	High
• Accessibility	See above	High
• Reproducibility	Results may differ as activity patterns change over time, data are from surveys Information on questionnaires and interviews were not provided	Medium
• Focus on factor of interest	Assume that survey questions are basic – days per year on average spent at work	High
• Representativeness of study population	Study is based on survey data of biological workers	High
• Primary data	Three studies	High
• Currency	Study was published within 10 years	Medium
• Adequacy of data collection period	Not considered to be a critical factor in biasing the survey results	High
• Validity of approach	Approach is based on questionnaires and interviews	High
• Study size	Study group size is small (n = 33)	Low
• Characterization of variability	The AM (225 days/yr) is slightly greater than the CTE reported by the Bureau of Labor Statistics for all occupations (219 days/yr) Standard deviation is from the study, and suggests that variance is low for this variable	Medium
• Lack of bias in study design	No basis for evaluation	None
• Measurement error	Potential error associated with recall, unless records are reviewed	Medium
Other Elements		
• Number of studies	Three, despite small sample size studies are adequate	Medium
• Agreement between researchers	U S Fish and Wildlife study data are presumed to be well reviewed General agreement that study data are relevant	Medium
Overall Confidence Rating	Site data support intuition about employment patters during the year for full time workers Variance from three studies is small, despite small sample size Uncertainty in truncation limits, especially on the low end	Medium

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A.2.3 EXPOSURE DURATION

For the Wildlife Refuge Worker scenario, exposure duration represents the number of years that a refuge worker spends on site The U S Bureau of Labor Statistics maintains National Survey Data on occupational activity patterns The Superfund default RME estimate for both full time and part-time workers is 25 years, based on the 95th percentile of the number of years worked at the same location reported in 1990

There is a wide range of reported job tenures among different categories of occupations The *Exposure Factors Handbook* (U S EPA, 1997, Table 15A-7) summarizes data reported by Carey (1988) for 109 million adults (16+ years) The median job tenure for the entire survey (all ages, male and female) is 6 6 years, however this varies by occupation and age Examples of median job tenure for selected occupations are given in Table A-42

Table A-42 Median job tenure for selected occupations based on Carey (1988) as reported in the *Exposure Factors Handbook* (U S EPA, 1997, Table 15A-7)

Occupation	Median Tenure (yrs)	Occupation	Median Tenure (yrs)
Barbers	24 8	Health technologists and technicians	6 3
Farmers, except horticulture	21 1	Supervisors, agricultural operations	5 2
Construction inspectors	10 7	Machine operators	4 5
Administrators and officials, public admin	8 9	Biological technicians	4 4
Surveying and mapping technicians	8 6	Animal caretakers, except farm	3 5
Science technicians	7 0	Information clerks	2 7

The major limitation in using these data to estimate exposure duration for risk assessment is that they reflect time spent in an occupation rather than time spent at a particular job site In addition, these data reflect median job tenures, whereas the complete distribution of tenures within a category is of interest Ideally, a sub-category representative of wildlife refuge workers at one site would be used to estimate exposure duration Such occupation-specific information has been obtained by the U S Fish and Wildlife Service in a National Wildlife Refuge Survey, in which wildlife refuge workers were interviewed from three refuges (Crab Orchard, IL, Malheur, OR, and Minnesota Valley, MN) Data for 80 wildlife refuge workers are summarized in the Rocky Mountain Arsenal report (Ebasco, 1994) Of these workers, 33 values reflect incomplete tenures, and 47 values reflect completed tenures The responses allow for estimates of years spent at one refuge, regardless of whether job activities changed While the sample size is relatively small, the estimates are similar to that of the National Survey Data, and provide a more occupation-specific data set for the exposure scenario characterized in this analysis

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A.2 3.1 PROBABILITY DISTRIBUTION FOR EXPOSURE DURATION

This report recommends the following probability distribution for use in risk equations that are based on EPA *Risk Assessment Guidance for Superfund* (U S EPA, 1989) in order to characterize *interindividual* variability in exposure duration among wildlife refuge workers

ED ~ Truncated Normal (7.18, 7, 0, 40) years

The truncated normal distribution is defined by four parameters

- arithmetic mean 7 18 years
- arithmetic standard deviation 7 years
- minimum 0 years
- maximum 40 years

The probability distribution (PDF and cumulative distribution function) is shown in Figure A-19 Given that a normal distribution has infinite lower and upper tails, it is reasonable to truncate the distribution at plausible bounds A minimum of zero was chosen to avoid negative values, and a maximum of 40 years was chosen to be approximately five standard deviations from the mean, so as to minimize the effect on the parameter estimates in the Monte Carlo simulation The effect of the truncation limit is to alter the original parameter estimates (mean, SD) to (9 1, 5 6), an increase of 27% in the mean and reduction of 27% in the SD It is clear from Figure A-20 that the truncation limit reduces a significant fraction of the low-end values, in such cases, it is generally preferable to use an alternative distribution that requires less truncation (e g , lognormal) This was not done for this analysis given that the data were not reported in a manner that would allow for exploration of alternative probability density functions

The 50^{th}, 90^{th}, 95^{th}, and 99^{th} percentiles of this distribution are 7 2, 16 2, 18 7, and 23 5 years, respectively

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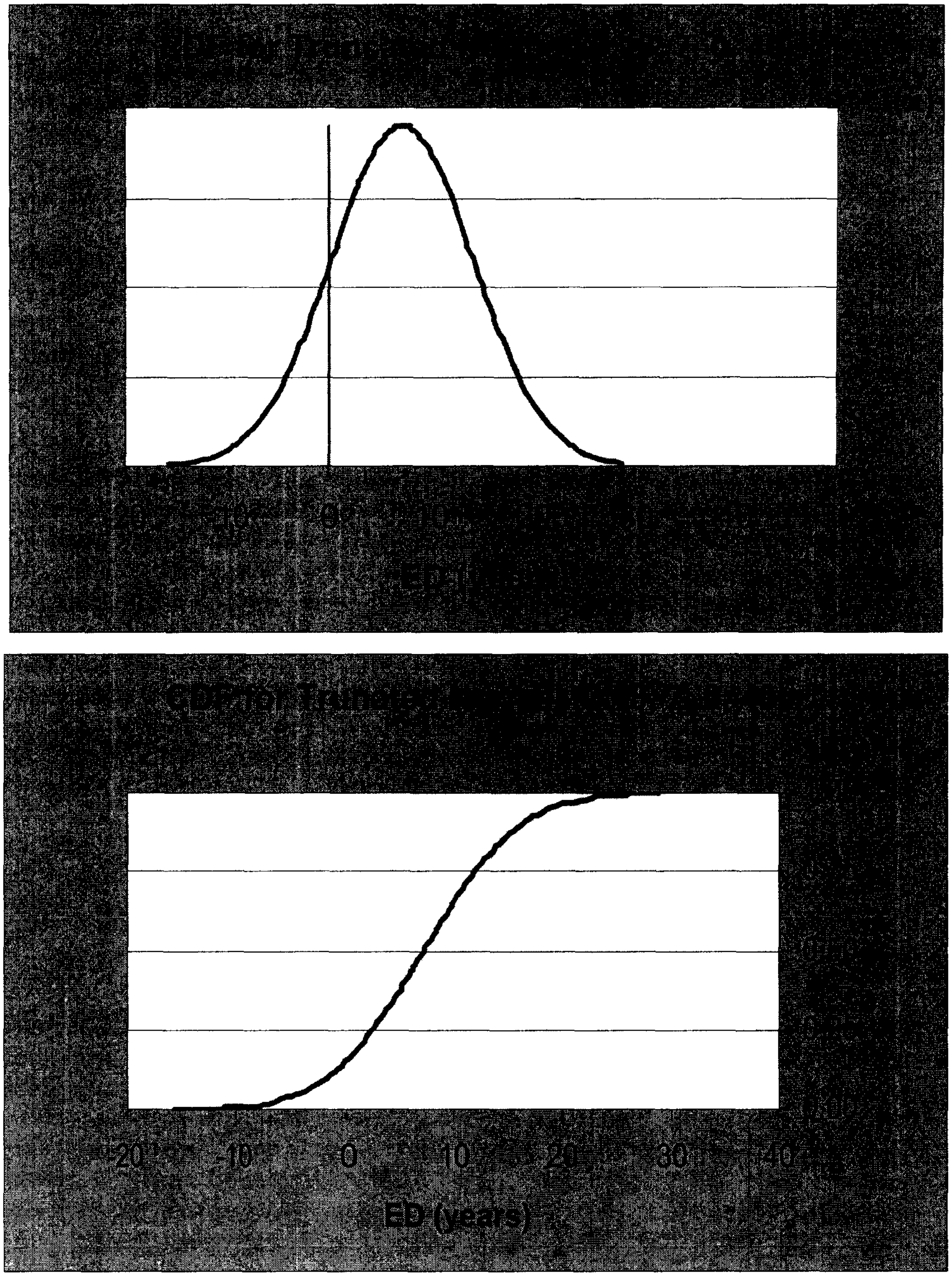

Figure A-20 Probability density function and cumulative distribution function views of the truncated normal distribution for exposure duration (years) for the wildlife refuge worker

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A.2.3.2 UNCERTAINTIES IN THE EXPOSURE DURATION PROBABILITY DISTRIBUTION

The use of a truncated normal distribution is supported by the data reported in the Rocky Mountain Arsenal by U S Fish and Wildlife on wildlife refuge workers in three different locations (Ebasco, 1994) Data from Carey et al (1988) for the U S population suggest that the highest median tenure at one job is less than 30 years, and the median tenure of all occupations is 6 6 years The tenure for biological technicians is reported to be 4 4 years The use of a normal distribution is professional judgment given the reported AM and SD for n = 33 biological refuge workers (or 80 tenures) The U S Fish and Wildlife Service fit the normal distribution to these data, although an alternative bounded distribution (e g , beta, lognormal) may be preferable given the significant fraction of low-end values that are truncated below 0

Table A-43. Confidence ratings for exposure duration for Wildlife Refuge Worker scenario

Considerations	Rationale	**Rating**
Study Elements		
• Level of peer review	U S Fish and Wildlife survey of biological workers reported in Rocky Mountain Arsenal report Supplemental data for verification available from U S Bureau of Census, U S EPA, and National Center for Health Statistics review of National Survey Data Relevant analyses of census data in three major studies are in the peer review literature	High
• Accessibility	See above	High
• Reproducibility	Results may differ as activity patterns change over time, data are from surveys Information on questionnaires and interviews were not provided	Medium
• Focus on factor of interest	Survey provides information on relevant cross-section of population at specific points in time, but not designed to follow workers through time Uncertainty in extrapolating from current employment duration to total employment duration	Medium
• Representativeness of study population	Study is based on survey data of biological workers	High
• Primary data	Three studies	Medium
• Currency	Study was published within 10 years	Medium
• Adequacy of data collection period	Not considered to be a critical factor in biasing the survey results	Medium
• Validity of approach	Uncertainty in total occupational period because survey data indicate years on job Questionnaires and interviews	Medium
• Study size	Study group is small (n = 33)	Low
• Characterization of variability	Mean and variance are from study data, truncation limits are professional judgment that values are nonnegative and within 5 SD's of the mean most often	High
• Lack of bias in study design	No basis for evaluation	Medium

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Considerations	Rationale	Rating
• Measurement error	Potential error associated with recall	High
Other Elements		
• Number of studies	Three, despite small sample size	High
• Agreement between researchers	U S Fish and Wildlife study data are presumed to be well reviewed General agreement that study data are relevant	Medium
Overall Confidence Rating	Assumed to be a conservative (biased high) estimate of duration at the same job Uncertainty due to small sample size and extrapolation to upper truncation limit	Medium

A.2.4 MASS LOADING

The probability distribution for this exposure variable is the same as described in the rural resident scenario (see Section A 1 9)

A.2.5 ADULT SOIL INGESTION

The basis for the uniform probability distribution for this exposure variable is the same as described in the rural resident scenario (see Section A 1 1) For the Wildlife Refuge Worker scenario, however, an additional time factor is introduced – exposure time Because RESRAD cannot account for this factor explicitly in the estimate of a time-weighted average dose, it is necessary to adjust the ingestion rate factor upwards to allocate an 8-hour activity over a 24-hour period The approach for rescaling the uniform distribution for ingestion rate is described below

A 2.5.1 RESCALING THE UNIFORM DISTRIBUTION FOR EACH LAND USE SCENARIO IN RESRAD

Although the probability distribution for soil ingestion rate presented above is considered to be equally applicable for each land use scenario, in RESRAD the input parameters need to be rescaled to reflect a different approach to calculating a time-weighted average dose The calculations using the EPA Standard Risk equations do not require the same rescaling since they explicitly include variables for exposure time and exposure frequency By contrast, RESRAD accounts for these terms in the soil ingestion rate term, as well as terms representing Indoor Time Fraction, and Outdoor Time Fraction (explained below) The difference in model structure between RESRAD and EPA Standard Risk equations has no impact on the point estimate calculations, but it does introduce minor differences in the overall variability in dose (and risk) estimated with the probabilistic assessment

A 2 5.2 RESCALING SOIL INGESTION RATE FOR WILDLIFE REFUGE WORKER SCENARIO

In RESRAD, for the Wildlife Refuge Worker scenario, the average daily soil ingestion rate needs to be allocated over a one-year period As with the Standard Risk equations, ingestion of contaminated soil is assumed to occur only during the work period The amount of time spent at work can be converted to an equivalent daily period based on the exposure time (hours/day) For simplicity, a point estimate for exposure time (8-hours/day) was used to rescale the parameters Accordingly, the parameters of the uniform distribution (minimum and maximum) were rescaled with the following multiplier

$$\frac{\text{Ingestion Rate}}{8\,\text{hrs}/\text{day}} = \frac{X}{24\,\text{hrs}/\text{day}}$$

$$X = \frac{24\,\text{hrs}/\text{day}}{8\,\text{hrs}/\text{day}} \times \text{Ingestion Rate} = 3\ 0 \times \text{Ingestion Rate}$$

Therefore, the equivalent parameters of the uniform distribution for RESRAD are as follows

- minimum 3 0 x 0 g/yr = 0 g/yr
- maximum 3 0 x 47 45 g/yr = 142 35g/yr

Despite using different parameters for the uniform distribution for soil ingestion rate, the input to RESRAD will yield the same effective point estimate of dose as the Standard Risk equation In addition to a soil ingestion rate term, RESRAD also has input variables for the following Indoor Time Fraction (IdF) and Outdoor Time Fraction (OdF) These variables refer to the fraction of time during a year the receptor is indoors or outdoors, *and* on site (in the contaminated area) Knowledge of the exposure time and exposure frequency is needed to calculate these terms In general, they will not sum to 1 0, unless the receptor is assumed to be on site continuously (i e , 24-hours per day, 365 days per year) The rural resident is assumed to be on site 24-hours/day, but not 365 days/yr Since the unit conversion for soil ingestion rate parameters between Standard Risk equations inputs and RESRAD inputs depends only on the exposure time, no conversion is needed for the Rural Resident scenario, as presented above

In the Wildlife Refuge Worker scenario, workers are assumed to spend half of their time indoors while on site This information is used in the derivation of the average annual mass of soil ingested indoors on site for both the RESRAD and Standard Risk equations to highlight similarities and differences of the two modeling approaches

Assuming an exposure frequency of 250 days/yr, the following input value is calculated for IdF for RESRAD

$$\text{IdF} = \text{Fraction of Time Indoors While On Site} \times \text{Fraction of Time On Site}$$

$$= (0\ 50) \times \left[\frac{\text{exposure time}}{24\text{hrs/day}} \times \frac{\text{exposure frequency}}{365\,\text{days/yr}}\right]$$

$$= 0\ 50 \times \frac{8}{24} \times \frac{250}{365} = 0\ 114$$

For RESRAD, the average annual mass of soil ingested indoors on site is equal to the product of soil ingestion rate and IdF (142 35 g/yr x 0 114), or 16 25 g/yr It should be noted that the

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exposure tıme appears ın both the derıvatıon of the soıl ıngestıon rate (denomınator) and the IdF term (numerator), effectıvely cancelıng out exposure tıme from the equatıon For the Standard Rısk equatıon approach, the average annual mass of soıl ıngested ındoors ıs equal to the product of soıl ıngestıon rate, exposure frequency, and IdF (130 mg/day x 001 g/mg x 250 days/yr x 0 50), or 16 25 g/yr In additıon, a second factor can be added to account for the reduced transport of materıal ındoors ıf wındows are shut for most of the day (e g , office space) Thıs factor ıs referred to as the ındoor dust-shıeldıng factor

The same calculatıon applıes to the soıl ıngested outdoors When poınt estımates are used for soıl ıngestıon rate and the tıme averagıng varıables (exposure tıme, exposure frequency), RESRAD and Standard Rısk equatıons wıll yıeld the same result It should be noted, however, that ın the probabılıstıc analysıs usıng the Standard Rısk calculatıons, the same poınt estımate ıs used for exposure tıme (8 hours/day), but exposure frequency ıs descrıbed by a normal probabılıty dıstrıbutıon (mean = 233 days/yr, SD = 10 days/yr) wıth an upper truncatıon lımıt (maxımum) equal to 250 days/yr In RESRAD, IdF and OdF are characterızed as poınt estımates, thereby reducıng the varıabılıty ın the dose Sınce the *maxımum* value for exposure frequency was selected as the poınt estımate to derıve IdF and OdF for the Wıldlıfe Refuge Worker scenarıo, on average, RESRAD wıll tend to yıeld a slıghtly hıgher estımate of soıl ıngestıon than the Standard Rısk equatıons

A.3.0 INHALATION RATE (IR_AIR) FOR THE OFFICE WORKER

A poınt estımate value of 1 1 m^3/hr was used ın the 1998 Rocky Flats Programmatıc Prelımınary Remedıatıon Goal (PPRG) spreadsheets Thıs value ıs based on the Internatıonal Commıssıon on Radıologıcal Protectıon (ICRP) value for ınhalatıon rate for sedentary workers (ICRP, 1979) In order to achıeve the proper apportıonment for RESRAD 6 0, thıs rate ıs assumed to be constant for the entıre year, resultıng ın the value of 9,636 m^3/yr, whıch was used as RESRAD ınput

A.3.1 EXPOSURE FREQUENCY FOR THE OFFICE WORKER

The poınt estımate value of 250 days/yr used ın thıs assessment ıs from the 1998 Rocky Flats PPRG spreadsheets Thıs value corresponds to U S EPA's RME value, whıch ıs vıewed as a reasonable upper bound for ındıvıduals who work weekdays only and take two weeks of vacatıon per year

A.3.2 EXPOSURE DURATION FOR THE OFFICE WORKER

The poınt estımate value of 25 years used ın thıs assessment ıs from the 1998 Rocky Flats PPRG spreadsheets Thıs value ıs the standard U S EPA RME default for occupatıonal/commercıal workers (U S EPA, 1991a)

A.3.3 SOIL INGESTION RATE FOR THE OFFICE WORKER

A poınt estımate approach was used to calculate dose and rısk for the Office Worker scenarıo For adult soıl ıngestıon rate, 50 mg/day was selected to represent the RME ındıvıdual ın the

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workplace, consistent with the EPA *Risk Assessment Guidance for Superfund, Supplemental Guidance, "Standard Default Exposure Factors"* (U S EPA, 1991a) Like the wildlife refuge worker, office workers are assumed to work 8-hours per day, 250 days a year Therefore, the point estimate for soil ingestion rate for the Office Worker scenario in RESRAD is calculated as (8 0 x 50 mg/day x 0 001 g/mg x 365 days/yr), or 54 75 g/yr

A.4.0 INHALATION RATE (IR_AIR) FOR THE OPEN SPACE USER

Point estimate values of 2 4 and 1 6 m^3/hr were used for the adult and child, respectively for periods spent on the site In order to achieve the proper apportionment for RESRAD 6 0 these rates must be assumed to be constant for the entire year, resulting in values of 21,024 and 14,016 m^3/yr, which were used as RESRAD inputs Because the RESRAD limiting value for inhalation rate is 20,000 m^3/yr, this value was used for the adult open space user, with an estimated under prediction of total dose on the order of 1%, since the inhalation pathway contributes little to the total dose

A.4.1 EXPOSURE FREQUENCY FOR THE OPEN SPACE USER

The point estimate value of 100 days/yr used in this assessment is from the 1998 Rocky Flats PPRG spreadsheets This value is the 95th percentile of the number of visits per year as determined in a survey conducted by Jefferson County Open Space in 1996

A.4.2 EXPOSURE DURATION FOR THE OPEN SPACE USER

The point estimate value of 30 years used in this assessment is from the 1998 Rocky Flats PPRG spreadsheets This value is the standard U S EPA RME defaults for residential receptors (U S EPA, 1991a)

A.4.3 SOIL INGESTION RATE FOR THE OPEN SPACE USER

A point estimate approach was used to calculate dose and risk for the Open Space User scenario For adult soil ingestion rate, 50 mg/day was selected to represent the reasonable maximum exposed individual in the workplace, consistent with the *EPA Risk Assessment Guidance for Superfund, Supplemental Guidance, Standard Default Exposure Factors* (U S EPA, 1991a) Adult and child open space users are assumed to visit 100 times a year and spend an average of 2 5 hours per visit on site A point estimate of 50 mg/day for the Standard Risk equation can be converted to an equivalent value for use in RESRAD by applying the exposure time as a rescaling multiplier, as discussed in the section on the Wildlife Refuge Worker scenario above

$$\frac{\text{Ingestion Rate}}{2\ 5\,\text{hrs}/\text{day}} = \frac{X}{24\,\text{hrs}/\text{day}}$$

$$X = \frac{24\,\text{hrs}/\text{day}}{2\ 5\,\text{hrs}/\text{day}} \times \text{Ingestion Rate} = 9\ 6 \times \text{Ingestion Rate}$$

Therefore, the point estimate for soil ingestion rate for the adult open space user in RESRAD is calculated as (9 6 x 50 mg/day x 0 001 g/mg x 365 days/yr), or 175 2 g/yr Similarly, for the child open space user, the RME point estimate is assumed to be 100 mg/day, twice that of adults For RESRAD, the equivalent point estimate is 175 2 g/yr x 2, or 350 4 g/yr

A.5.0 AREA OF THE CONTAMINATED ZONE

The RESRAD computer model performs two main calculations to assess the impacts of radionuclides in soil (1) a dose (or risk) calculation based upon soil concentrations of radionuclides which are input into the model (which could be thought of as the site conditions before cleanup), and (2) an RSAL calculation which is based upon the inherent properties of the radionuclides identified as contaminants coupled with the other physical properties of the site (site conditions after cleanup to the RSAL value) In both cases the RESRAD model simplifies the calculation by assuming that the contamination is uniformly present throughout the area of the contaminated zone, which is an area in square meters (circular or other specified shape) presented as an input parameter

The assumption of uniform contamination is oversimplified when applied to a dose calculation at a site before cleanup, since the contamination is rarely uniformly distributed (Performing multiple RESRAD runs on increments of the area of consideration, which are contaminated at different concentrations, and combining the results often addresses such a problem) However, the assumption of uniform contamination is both reasonable and conservative when applied to the RSAL calculation, for a site after cleanup Particularly, it is a conservative assumption, because, in assuming uniform contamination, it overestimates the actual situation (where some of the contaminated area has been cleaned up to below the RSAL value) Since the purpose of this Task is the computation of dose and risk based RSALs, the use of the RESRAD model with this assumption should not give cause for concern

The area of the contaminated zone has been identified as an important parameter in Chapter 4 for the combined pathway sensitivity analysis Inspection of the mathematical formulas used by RESRAD for each pathway (Yu et al , 2001) shows that all pathways are independent of area, except the air inhalation and gamma exposure pathways Moreover, work with the RESRAD gamma exposure pathway shows that it "saturates" at relatively small areas (less than 1,000 m^2 or about one fourth acre) This is understandable, since the exposure rate from gamma emitters drops off rapidly (inverse square law) with distance from the source

The inhalation pathway, investigated alone, saturates relatively slowly due to the effect of the area of the contamination zone on the area dilution factor used by versions of RESRAD later than 4 65 When taken in combination with all other pathways, however, it is seen that the slow saturation of the inhalation pathway contributes very little to the total dose, which is dominated by soil and plant ingestion contributions (both area-independent) Selection of the value of 1,400,000 m^2 for the circular area of the contaminated zone (the area known to be contaminated above 10 pCi/g of plutonium at Rocky Flats), assures that the combined pathway analysis is based upon saturation conditions

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A.5.1 DENSITY OF CONTAMINATED ZONE

The density of the contaminated zone is 1 8 g/cm^3, which is the rounded average bulk density for the Rocky Flats Alluvium (Table A-44) The dry bulk density measurements summarized below are taken from the following reports

- French Drain Geotechnical Investigation (EG&G, 1990)
- Operable Unit (OU) 1 Phase III RFI/RI Report (DOE, 1994)
- OU4 IM/IRA Environmental Assessment Decision Document (DOE, 1994)
- OU2 Phase II RFI/RI Report (EG&G, 1995)
- Groundwater Recharge Study (EG&G, 1993)
- Geotechnical Engineering Study, Sewer Line Installation South of Central Avenue (Huntington, 1994)
- Geotechnical Engineering Investigation Report Addendum, Title III Waste Management Facility Design (Merrick & Co , 1995)
- Preliminary Conceptual Design Document for Sanitary Landfill (Merrick & Co , 1990)
- Geotechnical Investigation Report of OU5 (DOE, 1995)

Table A-44 Dry bulk density of Rocky Flats alluvium

Number of Measurements	Average (g/cm^3)	Range (g/cm^3)	Standard Deviation
90	1 68	0 95 – 2 18	0 257

These measurements are from intervals deeper than the 15 cm depth of the contaminated zone and are therefore likely to be higher than densities typical of the contaminated zone The more dense the soil, the more activity per volume of soil and the greater the potential dose due to external irradiation At the same time, as soil becomes more dense the attenuation of external radiation from below the surface increases

A.5.2 THICKNESS OF CONTAMINATED ZONE

More than 90% of the Pu-239/240 and Am-241 radioactivity measured in soil profiles for OU2 is contained in the upper 0 12 m, regardless of soil type or location Near-surface physical activities (e g , freeze-thaw cycles) and biological activities (e g , earthworms and macropores along decayed root channels) are considered the most important factors in the vertical distribution of actinides at Rocky Flats The thickness of this zone has been set at 0 15 m, which corresponds to both the RFCA definition of surface soil and the default surface soil depth typically found in EPA guidance (U S EPA, 1992) In spite of the recognition that the surface soil concentrations are typically measured in the top 0 05 m, with exponentially decreasing concentration with depth, no credit was taken for the dilution of this surface contamination through the 0 15 m depth Such dilution would reduce the effective concentration of radioactivity in this deeper layer

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A.5.3 DEPTH OF ROOTS

The depth of roots (d_r) is set at 0 15 m, equal to the thickness of the contaminated zone (T) The cover and depth factor for root uptake ($FCD_{p1}(t)$), therefore, is equal to one (no effect) If d_r is greater than T, a portion of the roots is outside the contaminated zone and the amount of root uptake would be fractionated by the ratio of the two intervals (T/d_r) This root depth conservatively assumes that all roots are within the contaminated zone As has been discussed in Chapter 4, when all roots lie within the contaminated zone, the apparent sensitivity of both the thickness of the contaminated zone, and the depth of roots vanishes

A.5.4 DEPTH OF SOIL MIXING LAYER.

As discussed in Chapter 4 on sensitivity analysis, the Depth of Soil Mixing Layer has been chosen to be the same as the thickness of the contaminated zone, 0 15 m, in order to conservatively address the impact of this parameter on the amount of material available for resuspension

APPENDIX B
DESCRIPTION OF EPA'S RISK ASSESSMENT EQUATIONS

The following summary gives the risk equations by exposure pathways that were used to calculate risk given a concentration in soil (C_{soil}) In the Excel spreadsheets, the risk equations were rearranged to solve for RSALS Also included in the Excel spreadsheets is a summary worksheet that gives the point estimates and probability distributions used in these equations These equations apply to radionuclide exposure See Section 7 5 1 for further discussion of concepts related to the risk model and terminology

B.1.0 RISK EQUATIONS FOR RESIDENTIAL SCENARIO

Receptor Population	combined child (0 to 6 yrs) and adult (7+ yrs)
Health Endpoint	cancer risk (chronic exposure) and non-cancer hazard index
Exposure Pathways	inhalation, soil ingestion, homegrown diet, external exposure

Inhalation Pathway

$$Risk_{inhalation} = C_{soil} \times IR_{a\_age} \times ED \times EF \times \frac{ET}{24} \times ML \times CF_1 \times [ET_0 + ET_i \times DF_i] \times SF_{inh}$$

where,

$Risk_{inhalation}$	= excess lifetime cancer risk from inhalation of radionuclide
C_{soil}	= concentration in soil (pCi/g)
IR_{a_age}	= age-adjusted inhalation rate (m^3/day) (see below)
ED	= exposure duration for chronic exposure (yr)
EF	= exposure frequency (day/yr)
ET	= exposure time at residence (hrs/day) [divided by 24 hrs/day]
ML	= mass loading ($\mu g/m^3$)
CF_1	= conversion factor (10^{-6} g/μg)
ET_o	= exposure time fraction, outdoors (unitless)
ET_i	= exposure time fraction, indoors (unitless)
DF_i	= dilution factor for indoor inhalation (unitless)
SF_{inh}	= inhalation slope factor (risk/pCi)

$$IR_{a\_age} = \frac{(IR_{a\_child} \times ED_{child}) + (IR_{a\_adult} \times ED_{adult})}{ED}$$

where,

IR_{a_child}	= inhalation rate for children (m^3/day)
IR_{a_adult}	= inhalation rate for adults (m^3/day)
ED_{child}	= exposure duration during childhood (yr)
ED_{adult}	= exposure duration during adulthood (yr)

Residential Scenario (cont'd)

Soil Ingestion Pathway

$$Risk_{soil} = C_{soil} \times IR_{s\_age} \times ED \times EF \times CF_2 \times SF_{soil}$$

$$HI_{soil} = \frac{C_{soil} \times IR_{s\_age} \times ED \times EF \times CF_3}{BW_{age} \times 365 \times RfD_{oral}}$$

where,

$Risk_{soil}$	=	excess lifetime cancer risk from ingestion of radionuclide in soil
HI_{soil}	=	hazard index, noncancer risk from ingestion of chemical in soil
C_{soil}	=	concentration in soil (pCi/g for radionuclide, µg/g for chemical)
$^*IR_{s\_age}$	=	age-adjusted soil ingestion rate (mg/day)
ED	=	exposure duration (yr)
EF	=	exposure frequency (day/yr)
CF_2	=	conversion factor (10^{-3} g/mg)
CF_3	=	conversion factor (10^{-6} g/µg)
SF_{soil}	=	oral slope factor (risk/pCi)
BW_{age}	=	age-specific body weight (kg)
RfD_{oral}	=	oral reference dose (mg/kg-day)

*Note that ingestion rates are age-specific, so each ingestion rate is estimated for both children and adults, and weighted based on exposure duration

$$IR_{s\_age} = \frac{\left(IR_{s\_child} \times ED_{child}\right) + \left(IR_{s\_adult} \times ED_{adult}\right)}{ED}$$

where,

IR_{s_child}	=	ingestion rate for children (mg/day)
IR_{s_adult}	=	ingestion rate for adults (mg/day)
ED_{child}	=	exposure duration during childhood (yr)
ED_{adult}	=	exposure duration during adulthood (yr)

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Food Ingestion Pathway

$$Risk_{food} = \left(C_{pv} + C_{pr} + C_{pd}\right) \times CR_{food} \times ED \times SF_0$$

$$HI_{food} = \frac{(C_{pv} + C_{pr} + C_{pd}) \times CR_{food} \times ED}{BW \times 365 \times RfD_{oral}}$$

where,

$Risk_{food}$	=	excess lifetime cancer risk from ingestion of radionuclide in homegrown fruit, vegetables, and grain
HI_{food}	=	hazard index, noncancer risk from ingestion of chemical in foods
C_{pv}	=	concentration in plant, vegetative fraction (pCi/kg)
C_{pr}	=	concentration in plant, root fraction (pCi/kg)
C_{pd}	=	concentration on plant, deposition fraction (pCi/kg)
CR_{food}	=	consumption rate of homegrown fruit, vegetables, and grain (kg/yr)
ED	=	exposure duration for combined child and adult (yr)
SF_o	=	oral slope factor (risk/pCi)
RfD_{oral}	=	oral reference dose (mg/kg-day)

$$C_{pv} = C_{soil} \times CF_1 \times B_v \times DWC_v \times F_v$$

where,

C_{soil}	=	concentration in soil (pCi/g)
CF_1	=	conversion factor (10^3 g/kg)
B_v	=	soil-plant conversion factor, vegetation (unitless)
DWC_v	=	dry weight conversion factor, vegetative (pCi/kg)
F_v	=	fraction of total vegetable intake from vegetative portion (unitless)

$$C_{pr} = C_{soil} \times CF_1 \times B_r \times DWC_r \times F_r$$

where,

C_{soil}	=	concentration in soil (pCi/g)
CF_1	=	conversion factor (10^3 g/kg)
B_r	=	soil-plant conversion factor, roots (unitless)
DWC_r	=	dry weight conversion factor, roots (pCi/kg)
F_r	=	fraction of total vegetable intake from root portion (F_r = 1-F_v) (unitless)

$$C_{pd} = C_{soil} \times ML_p \times LT$$

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where,

C_{soil} = preliminary remediation goal, concentration in soil (pCi/g)
ML_p = mass loading factor for plant surfaces (g/m^3)
*LT = lumping term for deposition (m^3/kg)

* Note that particle deposition on leaf surfaces is estimated with the following lumping term

$$LT = V_d \times \frac{r}{4} \times \frac{t_{1/2}}{\ln 2}$$

where,

V_d = settling velocity (m/sec) = 0 002
r = average particle surface area to mass ratio (m^2/kg) = 1 28, so (r/4 = 0 32 m^2/kg)
$t_{1/2}$ = half life for particle deposition (sec) = 1209600 or 14 days, so ($t_{1/2}$ / ln2 = 1745000 sec)

Solving for LT with the values above yields LT = 1116 8 = 1 12x10^3 m^3/kg

$$CR_{food} = CR_{veg} + CR_{fruit} + \left(CR_{grain} \times HG_{grain}\right)$$

where,

*CR_{food} = consumption rate of homegrown vegetables, fruit, and grain (kg/yr)
CR_{veg} = consumption rate of homegrown vegetables (kg/yr)
CR_{fruit} = consumption rate of homegrown fruit (kg/yr)
CR_{grain} = consumption rate of total grain (kg/yr)
HG_{grain} = homegrown fraction for grain (unit less)

*Note that ingestion rates are age-specific, so each consumption rate is estimated for both children and adults, and weighted based on exposure duration, as given by the following equation

Residential Scenario (cont'd)

$$CR_{i\_age} = \frac{\left(CR_{i\_child} \times ED_{child}\right) + \left(CR_{i\_adult} \times ED_{adult}\right)}{ED}$$

where,

CR_{i_age} = age-adjusted consumption rate of i^{th} food type (kg/yr)
CR_{i_child} = consumption rate of i^{th} food type for children (kg/yr)
CR_{i_adult} = consumption rate of i^{th} food type for adults (kg/yr)
ED_{child} = exposure duration during childhood (yr)
ED_{adult} = exposure duration during adulthood (yr)

External Exposure Pathway[2]

$$Risk_{ext} = C_{soil} \times ACF \times \left(\frac{EF}{365}\right) \times \left(\frac{ET}{24}\right) \times ED \times \left[ET_o + ET_i \times (1 - S_e)\right] \times SF_{ext}$$

where,

$Risk_{ext}$ = excess lifetime cancer risk from direct external exposure to radionuclide in soil
C_{soil} = concentration in soil (pCi/g)
ACF = area correction factor (unitless)
EF = exposure frequency (day/yr)
ED = exposure duration (yr)
ET = exposure time, total time onsite (hrs/day)
ET_o = exposure time fraction, outdoor (unitless)
ET_i = exposure time fraction, indoor (unitless)
S_e = gamma shielding factor (unitless)
SF_{ext} = oral slope factor (risk/yr per pCi/g)

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[2]Eq 4 of U S EPA 2000 *Soil Screening Guidance for Radionuclides* User's Guide EPA/540-R-00-007

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B.2.0 RISK EQUATIONS FOR OCCUPATIONAL SCENARIO (OFFICE, WILDLIFE REFUGE)

Receptor Population	adult (18+ yrs)
Health Endpoint	cancer (chronic exposure), noncancer (see Section B 1 for examples)
Exposure Pathways	inhalation, soil ingestion, external exposure

Inhalation Pathway

$$Risk_{inhalation} = C_{soil} \times IR \times ED \times EF \times ET \times ML \times CF_1 \times \left[ET_o + ET_i \times DF_i\right] \times SF_{inh}$$

where,

$Risk_{inhalation}$	=	excess lifetime cancer risk from inhalation of radionuclide
C_{soil}	=	concentration in soil (pCi/g)
IR	=	inhalation rate (m^3/hr)
ED	=	exposure duration for chronic exposure (yr)
EF	=	exposure frequency (day/yr)
ET	=	exposure time at workplace (hrs/day)
ML	=	mass loading (µg/m^3)
CF_1	=	conversion factor (10^{-6} g/µg)
ET_o	=	exposure time fraction, outdoors (unitless)
ET_i	=	exposure time fraction, indoors (unitless)
DF_i	=	dilution factor for indoor inhalation (unitless)
SF_{inh}	=	inhalation slope factor (risk/pCi)

Soil Ingestion Pathway

$$Risk_{soil} = C_{soil} \times IR_s \times ED \times EF \times CF_2 \times SF_{soil}$$

where,

$Risk_{soil}$	=	excess lifetime cancer risk from ingestion of radionuclide in soil
C_{soil}	=	concentration in soil (pCi/g)
IR_s	=	adult soil ingestion rate (mg/day)
ED	=	exposure duration (yr)
EF	=	exposure frequency (day/yr)
CF_2	=	conversion factor (10^{-3} g/mg)
SF_{soil}	=	oral slope factor (risk/pCi)

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Occupational Scenario (Office, Wildlife Refuge)

External Exposure Pathway

$$Risk_{ext} = C_{soil} \times ACF \times \left(\frac{EF}{365}\right) \times \left(\frac{ET}{24}\right) \times ED \times \left[ET_o + ET_i \times (1 - S_e)\right] \times SF_{ext}$$

where,

$Risk_{ext}$	=	excess lifetime cancer risk from direct external exposure to radionuclide in soil
C_{soil}	=	concentration in soil (pCi/g)
ACF	=	area correction factor (unitless)
EF	=	exposure frequency (day/yr)
ED	=	exposure duration (yr)
ET	=	exposure time, total time onsite (hrs/day)
ET_o	=	exposure time fraction, outdoor (unitless)
ET_i	=	exposure time fraction, indoor (unitless)
S_e	=	gamma shielding factor (unitless)
SF_{ext}	=	oral slope factor (risk/yr per pCi/g)

B.3.0 RISK EQUATIONS FOR OPEN SPACE USER

Receptor Population	combined child (0 to 6 yrs) and adult (7+ yrs)
Health Endpoint	cancer (chronic exposure)
Exposure Pathways	inhalation, soil ingestion, external exposure

Inhalation Pathway

$$Risk_{inhalation} = C_{soil} \times IR_{a\_age} \times ED \times EF \times ET \times ML \times CF_1 \times SF_{inh}$$

where,

$Risk_{inhalation}$	=	excess lifetime cancer risk from inhalation of radionuclide
C_{soil}	=	concentration in soil (pCi/g)
IR_{a_age}	=	age-adjusted inhalation rate (m^3/day) (see below)
ED	=	exposure duration for chronic exposure (yr)
EF	=	exposure frequency (day/yr)
ET	=	exposure time at open space (hrs/day)
ML	=	mass loading ($\mu g/m^3$)
CF_1	=	conversion factor (10^{-6} g/µg)
SF_{inh}	=	inhalation slope factor (risk/pCi)

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$$IR_{a\_age} = \frac{\left(IR_{a\_child} \times ED_{child}\right) + \left(IR_{a\_adult} \times ED_{adult}\right)}{ED}$$

where,

IR_{a_child}	=	inhalation rate for children (m^3/day)
IR_{a_adult}	=	inhalation rate for adults (m^3/day)
ED_{child}	=	exposure duration during childhood (yr)
ED_{adult}	=	exposure duration during adulthood (yr)

Soil Ingestion Pathway

$$Risk_{soil} = C_{soil} \times IR_{s\_age} \times ED \times EF \times CF_2 \times SF_{soil}$$

where,

$Risk_{soil}$	=	excess lifetime cancer risk from ingestion of radionuclide in soil
C_{soil}	=	concentration in soil (pCi/g)
*IR_{s_age}	=	age-adjusted soil ingestion rate (mg/day)
ED	=	exposure duration (yr)
EF	=	exposure frequency (day/yr)
CF_2	=	conversion factor (10^{-3} g/mg)
SF_{soil}	=	oral slope factor (risk/pCi)

*Note that ingestion rates are age-specific, so each ingestion rate is estimated for both children and adults, and weighted based on exposure duration

$$IR_{s\_age} = \frac{\left(IR_{s\_child} \times ED_{child}\right) + \left(IR_{s\_adult} \times ED_{adult}\right)}{ED}$$

where,

IR_{s_child}	=	inhalation rate for children (mg/day)
IR_{s_adult}	=	inhalation rate for adults (mg/day)
ED_{child}	=	exposure duration during childhood (yr)
ED_{adult}	=	exposure duration during adulthood (yr)

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External Exposure Pathway

$$Risk_{ext} = C_{soil} \times ACF \times \left(\frac{EF}{365}\right) \times \left(\frac{ET}{24}\right) \times ED \times \left[ET_o + ET_i \times (1 - S_e)\right] \times SF_{ext}$$

where,

$Risk_{ext}$	=	excess lifetime cancer risk from external exposure to radionuclide in soil
C_{soil}	=	concentration in soil (pCi/g)
ACF	=	area correction factor (unit less)
EF	=	exposure frequency (day/yr)
ED	=	exposure duration (yr)
ET	=	external time, total time onsite (hrs/day)
ET_o	=	exposure time fraction, outdoor (unitless)
ET_i	=	exposure time fraction, indoor (unitless)
S_e	=	gamma shielding factor (unitless)
SF_{ext}	=	oral slope factor (risk/yr per pCi/g)

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APPENDIX C
RISK BASED SPREADSHEETS AND INSTRUCTIONS FOR USE FOR PROBABILISTIC CALCULATIONS

This appendix describes the Excel spreadsheets that were developed to obtain both point estimates (i e , deterministic) and probabilistic estimates of risk and/or risk-based soil action levels (RSALs) In addition, instructions are provided on how to use Crystal Ball®, the add-in software to Excel needed to execute the Monte Carlo simulations and reproduce the results presented in the main report Appendix B presents a detailed description of the equations that were used to calculate risk given a soil concentration of each radionuclide These same equations were applied to calculate RSALs (by rearranging the equation to calculate RSAL given a target risk level) Appendix A presents a detailed description of the derivation of probability distributions and parameter values for exposure variables identified by the sensitivity analysis as important sources of variability or uncertainty Separate probabilistic calculations were conducted for each radionuclide, and a sum-of-ratios (SOR) calculation was then applied to selected percentile values of the RSAL distributions to determine the final SOR-adjusted RSALs

C.1.0 EXCEL SPREADSHEETS

Table C-1 lists the spreadsheets that were developed for calculating point estimates and probabilistic estimates of risk and RSAL A separate spreadsheet is available for each of the four exposure scenarios (1) Rural Resident, (2) Wildlife Refuge Worker, (3) Office Worker, and (4) Open Space User Examples of each spreadsheet are given in Figures C-4 to C-7

Table C-1 Excel spreadsheets developed for calculating risks and RSALs with EPA Standard Risk Methodology equations

Excel Spreadsheet	Exposure Scenario	Exposure Pathways			
		Inhalation	**Soil**	**Food**	**External**
EPA Standard Risk Methodology_resident xls	Rural Resident	X	X	X	X
EPA Standard Risk Methodology_wildlife xls	Wildlife Refuge Worker	X	X		X
EPA Standard Risk Methodology_office xls	Office Worker	X	X		X
EPA Standard Risk Methodology_open xls	Open Space User	X	X		X

The following features are available on each spreadsheet

(1) Calculate either **risk** or **RSAL** for each of the five radionuclides (i e , Am-241, Pu-239, U-234, U-235, U-238) The spreadsheet automatically sums risks across exposure pathways (see Table C-1), and calculates the percent contribution of each pathway

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(2) Select **pomt estımates** or **probabılıty dıstrıbutıons** for ınput varıables ın the equatıons by usıng the toggle provıded at the top of the spreadsheet (see Fıgure C-1) It ıs ımportant that the toggle be set to probabılıstıc estımates prıor to runnıng a Monte Carlo sımulatıon Instructıons for runnıng Monte Carlo sımulatıons wıth Crystal Ball® are gıven below

(3) Calculate the **percent contrıbutıon of each exposure pathway** for each radıonuclıde If the spreadsheet ıs used to calculate rısk, the user must specıfy a concentratıon (pCı/g) for the radıonuclıdes (ı e , cell **C3**) Thıs concentratıon ıs applıed to each radıonuclıde If the spreadsheet ıs used to calculate RSAL, the user must specıfy the Target Rısk level (e g , 1E-04, 1E-05, 1E-06) usıng cell **J4** Thıs target rısk ıs applıed to each radıonuclıde Two observatıons should be noted about these summary statıstıcs

a Because the percent contrıbutıon by pathway ıs ındependent of the chemıcal concentratıon that ıs selected, the results gıven ın cells **O6: R11** apply to both the rısk and RSAL calculatıons For example, usıng the poınt estımate settıng, and a soıl concentratıon for Am-241 of 100 pCı/g, the total rısk ıs 1 4E-04, and the percent contrıbutıon of the soıl ıngestıon pathway ıs 19 1% If the soıl concentratıon ıs doubled to 200 pCı/g, the total rısk doubles to 2 9E-04, but the percent contrıbutıon of the soıl pathway remaıns at 19 1%

b When the poınt estımate optıon ıs selected, there wıll always be only one set of results for a gıven choıce of soıl concentratıon or target rısk However, when a probabılıstıc estımate ıs selected, the spreadsheets wıll dısplay one set of random values for results Thıs means that every tıme the spreadsheet ıs reopened, a dıfferent set of values wıll be seen for the followıng* rısk results (cells **C6: G11**), ınput varıables (column **F**), percent contrıbutıon to rısk (cells **O6: R11**) In order to obtaın summary statıstıcs for the probabılıstıc approach, the user needs to run a Monte Carlo sımulatıon usıng Crystal Ball®

***NOTE** Crystal Ball® requıres a "place-holder cell" be set asıde for each ınput varıable Cells under the headıng "Probabılıty Dıstrıbutıon, Value" ın **column F** have been desıgnated as the "place holder cells" Thıs partıcular set of cells allows the computer program to select values from probabılıty dıstrıbutıons whıle runnıng a Monte Carlo sımulatıon The values ın these cells should be consıdered random, and should NOT be ınterpreted as havıng any correspondence wıth the poınt estımates that have been defıned for the ınput varıables See the warnıng note (>>>NOTE<<<) on each worksheet, as shown ın Fıgure C-1

(4) Comment fıelds have been extensıvely used ın each spreadsheet to provıde addıtıonal explanatıons to the user Cells wıth comment fıelds are denoted by the red trıangle ın the upper rıght corner For example, ın the EPA Standard Rısk Methodology_resıdent xls spreadsheet, the followıng comment ıs attached to cell **D16** to explaın the unıts for ınhalatıon rate *average daıly ınhalatıon rate gıven as m^3/24hr because exposure tıme may modıfy ıt*

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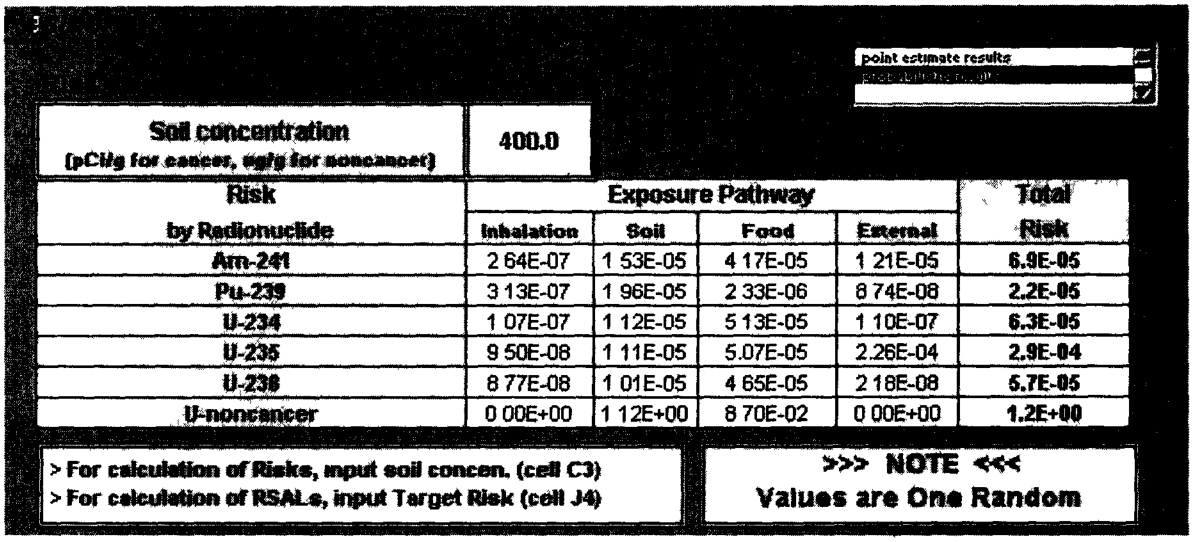
(5) The slope factors are provided in a separate tab in each spreadsheet called "toxicity" Several different references were evaluated to determine the appropriate slope

Point Estimates or Probabilistic Estimates

Instructions are provided at the beginning of each Excel spreadsheet to explain the steps in calculating point estimates or probabilistic estimates of risk or RSALs Table C-2 gives an example of the instructions for the Rural Resident scenario The following discussion provides the same information in more detail

Each spreadsheet can be used to calculate risk or RSAL using either point estimates or probability distributions A toggle is provided at the top of each spreadsheet, as shown in Figure C-1 It is important that this toggle be set to "probabilistic estimates" prior to running a Monte Carlo simulation



point estimate results

Soil concentration (pCi/g for cancer, ug/g for noncancer)	400.0				
Risk by Radionuclide	Exposure Pathway				Total Risk
	Inhalation	Soil	Food	External	
Am-241	2 64E-07	1 53E-05	4 17E-05	1 21E-05	6.9E-05
Pu-239	3 13E-07	1 96E-05	2 33E-06	8 74E-08	2.2E-05
U-234	1 07E-07	1 12E-05	5 13E-05	1 10E-07	6.3E-05
U-235	9 50E-08	1 11E-05	5.07E-05	2.26E-04	2.9E-04
U-238	8 77E-08	1 01E-05	4 65E-05	2 18E-08	5.7E-05
U-noncancer	0 00E+00	1 12E+00	8 70E-02	0 00E+00	1.2E+00

> For calculation of Risks, input soil concen. (cell C3)
> For calculation of RSALs, input Target Risk (cell J4)

>>> NOTE <<<
Values are One Random

Figure C-1. Toggle to select between point estimate results and probabilistic results for the Rural Resident scenario This is option should be selected first for each Excel Worksheet

Because pathway-specific calculations are given, the spreadsheets can also be used to calculate the percent contribution to the total risk (or RSAL) The total contribution is a function of both the exposure and toxicity variables for each radionuclide Table C-2 displays an example of the results for the Rural Resident scenario It should be noted that since the percent contribution is independent of the concentration in soil, the results would be the same regardless of whether the spreadsheet is used to calculate risk or RSAL The equations are set up to track the percent contributions for the forward-facing calculations of risk

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Table C-2 Results showing the percent contribution of exposure pathway by radionuclide The total sums to 100% for each radionuclide The example is from one iteration of a Monte Carlo simulation using the Excel worksheet for the Rural Resident exposure scenario

Risk by RAD	% Total by Exposure Pathway				Total %
	Inhalation	Soil	Food	External	
Am-241	0.4%	22.1%	60.1%	17.4%	100%
Pu-239	1.4%	87.8%	10.4%	0.4%	100%
U-234	0.2%	17.8%	81.8%	0.2%	100%
U-235	0.0%	3.9%	17.6%	78.5%	100%
U-238	0.2%	17.8%	82.0%	0.0%	100%
U-noncancer	0.0%	92.8%	7.2%	0.0%	100%

For the point estimate calculation, one set of final results will be displayed in the output range (e g , cells **O6: R11**) However, for the probabilistic simulations, one set of results represents one iteration (or trial) of the Monte Carlo simulation If a Monte Carlo simulation is run with 5,000 trials, the calculations will be repeated 5,000 times Therefore, when the worksheet is first opened, the numbers displayed for the "probabilistic results" should be interpreted with caution Each cell in this range can be tracked as a "forecast cell", as discussed below, so that summary statistics can be obtained after the simulation has ended Figure C-3 gives the probability distribution of percent contribution for the soil ingestion pathway for Am-241 under the Rural Resident scenario In this example, one would conclude that the average percent contribution of soil to the total risk of Am-241 is 16%, however, the 95th percentile is 37% These means that there is a 5% probability that soil contributes more than one third to the total risk of Am-241 for the rural resident population

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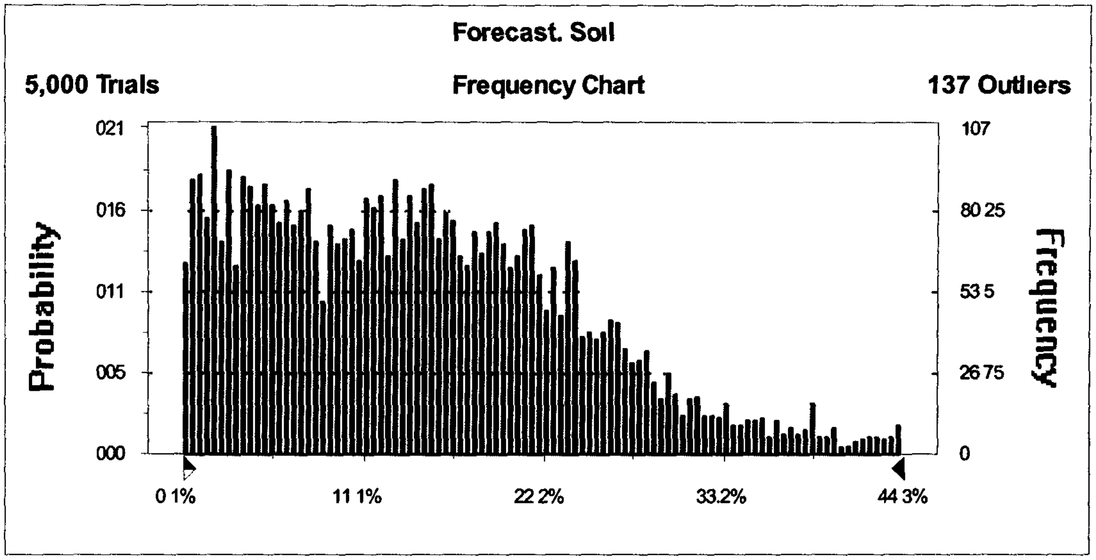

Figure C-2 Results of a Monte Carlo simulation with 5,000 iterations showing the probability distribution for the percent contribution of the soil ingestion pathway to total Am-241 Risk under the Rural Resident scenario The average contribution of the soil pathway is approximately 16%, while the 95th percentile is approximately 37%

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Table C-3 Example of Standard Risk equation spreadsheet for Rural Resident scenario showing point estimates and probability distributions The column labeled "Value" represents one random value selected from the specified probability distribution

Exposure Variable	Acronym	Units	Point Estimate	Value	Type	p1	p2	p3	p4
					Probability Distribution				
Inhalation rate, child	IRa_child	m^3/24 hr	8 3	6 9	**Lognormal**	9 3	2 9		
Inhalation rate, adult	IRa_adult	m^3/24 hr	20 0	15 9	**Lognormal**	16 2	3 9		
Age-adjusted inhalation rate	IRa_age	m^3/24 hr	17 7	6 9	*calculated*				
Exposure time	ET	hr/day	24	24	pt estimate				
Exposure time fraction, outdoors	ETo	unitless	0 145	0 15	pt estimate				
Exposure time fraction, indoors	ETi	unitless	0 855	0 85	pt estimate				
Dilution factor, indoor inhalation	DFi	unitless	0 7	0 7	pt estimate				
Exposure frequency	EF	day/yr	350	237 1	**Triangular**	175	234	350	
Exposure duration, combined	ED_age	yr	30 0	3 8	**T-Lognormal**	12 6	16 2	1	87
Exposure duration, child (1-6 yr)	ED_child	yr	6 0	3 8	*calculated*				
Exposure duration, adult (7-31 yr)	ED_adult	yr	24 0	0 0	*calculated*				
Mass loading	ML	ug/m^3	67 0	5 0	**Empirical CDF**	[{0, 20 2, 23 1 50 7 58 0 95 7, 109 5 200} {min, 0 338 0 788 0 919 0 944 0 969 0 994 max}]			
Soil ingestion rate, child	IRs_child	mg/day	200	194 4	**T-Lognormal**	47 5	112	0	1000
Soil ingestion rate, adult	IRs_adult	mg/day	100	100	**Uniform**	0	130		
Age-adjusted soil ingestion rate	IRs_age	mg/day	120 0	194 4	*calculated*				
Homegrown veg consumption rate, child	CR_v_child	kg/yr	10 57	1 1	**Lognormal**	10 57	50		
Homegrown veg consumption rate, adult	CR_v_adult	kg/yr	50	54 4	**Lognormal**	50	240		
Age-adjusted veg consumption rate	CR_veg	kg/yr	42 1	1 1	*calculated*				
Homegrown fruit consumption rate, child	CR_f_child	kg/yr	12 2	151 6	**Lognormal**	12 2	37 3		
Homegrown fruit consumption rate, adult	CR_f_adult	kg/yr	57	1 0	**Lognormal**	57	174		
Age-adjusted fruit consumption rate	CR_fruit	kg/yr	48 0	151 6	*calculated*				
Total grain consumption rate, child	CR_g_child	kg/yr	23 65	31 1	**Lognormal**	23 65	26 4		
Total grain consumption rate, adult	CR_g_adult	kg/yr	110	67 3	**Lognormal**	110	123		
Homegrown fraction of grain	HG_grain	unitless	0 01	0 01	pt estimate				
Age-adjusted grain consumption rate	CR_grain	kg/yr	0 93	0 6	*calculated*				
Total consumption rate (veg + fruit + grain)	CR_food	kg/yr	91 1	153 3	*calculated*				
Soil-to-plant conc ratio, veg	Bv	unitless	rad-specific	rad-specific	pt estimate				
Soil-to-plant conc ratio, roots	Br	unitless	rad-specific	rad-specific	pt estimate				
Dry weight conversion, veg	DWCv	unitless	0 07	0 07	pt estimate				
Dry weight conversion, roots	DWCr	unitless	0 20	0 20	pt estimate				
Fraction veg vs reproductive	Fv	unitless	0 149	0 149	pt estimate				
Conc in plant (veg)	Cpv	pCi/kg	rad-specific	rad-specific	*calculated*				
Conc in plant (root)	Cpr	pCi/kg	rad-specific	rad-specific	*calculated*				
Mass loading on plant	MLp	g/m3	1 675E-04	1 26E-05	*calculated*				
Lumping term for deposition	LT	m3/kg	1 12E+03	1 12E+03	pt estimate				
Conc on plant (deposition)	Cpd	pCi/kg	0 00	0 00	*calculated*				
Total concentration for plant	Cp	pCi/kg	rad-specific	rad-specific	*calculated*				
Area correction factor	ACF	unitless	0 9	0 9	pt estimate				
Gamma shielding factor	(1 - Se)	unitless	0 4	0 4	pt estimate				

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Table C-4 Example of Standard Risk equation spreadsheet for Wildlife Refuge Worker scenario showing point estimates and probability distributions The column labeled "Value" represents one random value selected from the specified probability distribution

Exposure Variable	Acronym	Units	Point Estimate	Value	Type	p1	p2	p3	p4
				Probability Distribution					
Hourly inhalation rate	V_out_hr	m^3/hr	1 3	0 5	Beta	1 79	3 06	1 1	2
Exposure time	ET	hr/day	8	8	pt estimate				
Exposure time fraction, outdoors	ETo	unitless	0 5	0 5	pt estimate				
Exposure time fraction, indoors	ETi	unitless	0 5	0 5	pt estimate				
Dilution factor, indoor inhalation	DFi	unitless	0 7	0 7	pt estimate				
Exposure frequency	EF	day/yr	250	233 5	T-Normal	225 00	10 23	200	250
Exposure duration	ED	yr	18 7	19 6	T-Normal	7 18	7 00	0	40
Mass loading	ML	ug/m^3	67 0	31 0	Empirical CDF	[{0, 20 2, 23 1, 50 7, 58 0, 95 7, 109 5, 200}, {min, 0 338, 0 788, 0 919, 0 944, 0 969, 0 994, max}]			
Soil ingestion rate - adult	IR_a	mg/day	100	44	Uniform	0	130		
Area correction factor	ACF	unitless	0 9	0 9	pt estimate				
Gamma shielding factor	(1 - Se)	unitless	0 4	0 4	pt estimate				

Table C-5 Example of Standard Risk equation spreadsheet for Office Worker scenario showing point estimates

Exposure Variable	Acronym	Units	Point Estimate	Value	Type	p1	p2	p3	p4
				Probability Distribution					
Hourly inhalation rate	V_out_hr	m3/hr	1 1	1 1	pt estimate				
Exposure time	ET	hr/day	8	8 0	pt estimate				
Exposure time fraction, outdoors	ETo	unitless	0	0 0	pt estimate				
Exposure time fraction, indoors	ETi	unitless	1	1 0	pt estimate				
Dilution factor, indoor inhalation	DFi	unitless	0 7	0 7	pt estimate				
Exposure frequency	EF	day/yr	250	250 0	pt estimate				
Exposure duration	ED	yr	25	25 0	pt estimate				
Mass loading	ML	ug/m^3	67 0	67 0	pt estimate				
Soil ingestion rate, adult	IR_a	mg/day	50	50 0	pt estimate				
Area Correction Factor	ACF	unitless	0 9	0 9	pt estimate				
Gamma shielding factor	(1 - Se)	unitless	0 4	0 4	pt estimate				

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Table C-6 Example of Standard Risk equation spreadsheet for Open Space User scenario showing point estimates

Exposure Variable	Acronym	Units	Point Estimate	Probability Distribution					
				Value	Type	p1	p2	p3	p4
Inhalation rate, adult	IRa_adult	m^3/hr	2 4	2 4	pt estimate				
Inhalation rate, child	IRa_child	m^3/hr	1 6	1 6	pt estimate				
Exposure time	ET	hr/day	2 5	2 5	pt estimate				
Exposure time fraction, outdoors	ETo	unitless	1 0	1 0	pt estimate				
Exposure time fraction, indoors	ETi	unitless	0 0	0 0	pt estimate				
Dilution factor, indoor inhalation	DFi	unitless	0 7	0 7	pt estimate				
Exposure frequency	EF	day/yr	100	100 0	pt estimate				
Exposure duration, child (1-6 yr)	ED	yr	6	6 0	pt estimate				
Exposure duration, adult (7-31 yr)	ED	yr	24	24 0	pt estimate				
Mass loading	ML	ug/m^3	67 0	67 0	pt estimate				
Soil ingestion rate, adult	IRs_adult	mg/day	50	50 0	pt estimate				
Soil ingestion rate, child	IRs_child	mg/day	100	100 0	pt estimate				
Area Correction Factor	ACF	unitless	0 9	0 9	pt estimate				
Gamma shielding factor	(1 - Se)	unitless	0 4	0 4	pt estimate				

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C.2.0 CRYSTAL BALL® SETTINGS AND INSTRUCTIONS

Instructions for obtaining both point estimate results and probabilistic results are given in each Excel worksheet An example for the Rural Resident scenario is given in Table C-7 The difference between the point estimate and probabilistic approaches is that under the point estimate approach, all of the input variables are described by a single fixed values, whereas the probabilistic results use a probability distribution for one or more input variables The same set of equations is used in both approaches

In order to run the Monte Carlo analysis with these worksheets, the following software was used Crystal Ball® 2000 Professional Edition version 5 1 (Decisioneering, 1986) Microsoft Excel 2000, and a Windows® 98 operating system While this appendix provides highlights of the steps required to run a Monte Carlo simulation, it is not intended to be a comprehensive tutorial or substitute for professional training classes in Monte Carlo analysis or probabilistic risk assessment

Steps 7 to 14 of the Instructions given in Table C-7 provide a step-by-step guide to running a Monte Carlo simulation It is highly recommended that one open a worksheet after having opened Crystal Ball® By opening Crystal Ball®, Excel will automatically open as well Choose to enable the macros when prompted After the spreadsheet is successfully opened, the important components of running an analysis can be divided into 4 major areas (1) Specifying probability distributions for one or more input variables, (2) Inputting the Settings to run a Monte Carlo analysis, (3) Specifying the cells that contain the output of interest, and (4) Running the simulation Table C-7 provides instructions for using the Crystal Ball® commands given in the pull-down menus of the toolbar Some of the same commands can be executed by using the short-cut icons in the toolbar that is added to the desktop after Crystal Ball® is opened (see Figure C-3)

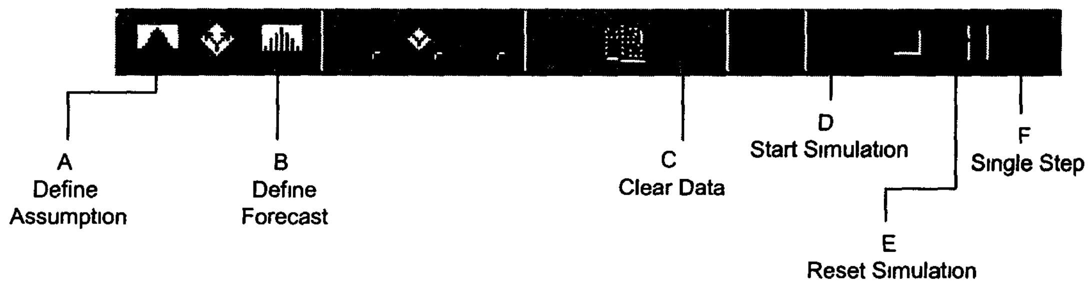

Figure C-3. Crystal Ball's® toolbar of short-cut icons that are added to the Microsoft Excel toolbar The following describes the function and purpose of each icon

A **Define Assumption** – used to define the type of probability distribution and the parameter values for the distribution In order to specify a distribution, a value is needed in a cell as a placeholder These cells are highlighted green in **Column F** First, click on the "place holder" cell in **Column F**, and then click this icon to view the distribution options If a distribution is already assigned, you will see a graph of the distribution, and references to

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cells on the spreadsheet that define the parameters (ı e , **Columns G:K** If a dıstrıbutıon ıs not yet assıgned, you wıll see a Gallery of optıons In each worksheet, pre-defined cells are hıghlıghted wıth green shadıng

B. Define Forecast – used to ındıcate whıch cell(s) to track durıng a Monte Carlo sımulatıon ın order to present a dıstrıbutıon of results Optıons ınclude rısk estımates, RSAL estımates, and percent contrıbutıons of exposure pathways by radıonuclıde

C. Clear Data – wıll remove a definıtıon of eıther an assumptıon (A) or a forecast (B) Sımply select the cell, and clıck on the ıcon Crystal Ball® wıll prompt the user to delete the definıtıons

D. Start Simulatıon – used to run a sımulatıon after the run preferences have been defined

E. Reset Sımulatıon – used to reset the Crystal Ball® sımulatıon to rerun a new sımulatıon Thıs optıon should **ALWAYS** be selected for consecutıve sımulatıons

F. Sıngle Step – used to run one ıteratıon Thıs ıs a useful feature to verıfy that random values are beıng selected for the desıred cells ın a spreadsheet It has a sımılar utılıty to the F9 key (Recalculate) ın Excel

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Table C-7. Example of "Instructions Sheet" provided for the Rural Resident exposure scenario

Instructions for Using Excel Spreadsheets to Calculate Risk or RSAL with U S EPA Standard Risk Equations

Step	Description	Action
1	To begin open the spreadsheet "Residential"	Click on the name at the bottom of this spreadsheet
2	Select type of calculation - point estimate or probabilistic	Click on 1 of 2 options in the dialogue box at the top of **Columns F & G**
If calculating point estimates, go to Steps 3-6 If calculating probabilistic estimates, skip to Steps 7-14		
3	Point Estimate Inputs - exposure and toxicity	Change values for exposure variables in **Column E** Change values for dose-response in "Toxicity" tab
4	Risk calculation	Enter soil concentration in Cell **C3** This value will apply equally to all radionuclides
5	RSAL calculation	Enter a target risk in Cell **J4** This value will apply equally to all radionuclides
6	Results - Risk RSAL % by Pathway	Risk estimates are given in cells **G6 G11** RSAL estimates are given in cells **J6 J11** % by exposure pathway are given in cells **O6 R11** these results apply equally to the risk or RSAL calculations
7	Monte Carlo simulations	Crystal Ball (CB) is needed to run Monte Carlo simulations If CB is not open exit Excel open CB and open this spreadsheet
8	Enter Probability Distribution Functions (PDFs) by Defining Assumptions	CB has a separate menu for inputting distributions CB requires a unique cell for each assignment of a distribution **Column F** called "Values" has been reserved for this purpose Cells that are defined as PDFs are shaded "green" whereas cells that are defined as point estimates have no shading The definition of the PDF is given in the adjacent cells in **Columns G K** To change parameter values simply change the values in **Columns H K** To change both the distribution type and parameter values click on the cell in **Column F** and choose "Cell / Define Assumptions from the menu bar then select Gallery
9	Choose Results to Track	Results that may be of interest risks RSALs % contribution by pathway Be sure to select the Probabilistic results" from the toggle in Columns **F&G** (See Step 2) > Risk estimates are given in cells **G6 G11** > RSAL estimates are given in cells **K6 K11** > % by exposure pathway are given in cells **O6 R11**
10	Define Forecasts	Before running a Monte Carlo simulation you need to identify which output cells to track Click on the cell you want to track from among the options in Step 9 Choose "Cell / Define Forecasts" from the menu bar Enter a unique name for the forecast cell (e g Am-241 Risk) Repeat for each Forecast cell
11	Monte Carlo simulation settings number of trials, sampling	Choose these settings prior to running the first Monte Carlo simulation Options are located in Run / Run preferences Click on Trials to set the number of trials (or iterations) Click on Sampling to set the sampling to Latin Hypercube Click on Speed and select options as desired to increase the sampling speed
12	Run a Monte Carlo Simulation	After the settings have been selected (see Step 11) run a simulation by clicking on the solid green arrow that points to the right on the menu bar or choose "Run / Run" To Rerun a simulation it is import to **RESET Crystal Ball** Do this by clicking on the double green arrows that point to the left on the menu bar
13	View Results	CB provides the following results automatically after a simulation is complete a graph showing the distribution of results summary statistics in increments of 10th percentiles A report can be generated by choosing Run / Create Report" Additional percentiles can be obtained If the statistic of interest is not generated by this report the data must be exported to Excel and calculated manually within Excel Export data by choosing "Run / Extract Data .
14	Obtain Exact Results	Every time a Monte Carlo simulation is run values are selected at random from the probability distributions defined as assumption cells Repeating simulations with the same number of iterations will give similar but not exactly the same results To obtain exactly reproducible results it is necessary to fix the random number seed and note all of the settings This option is available in " Run / Run Preferences then click on Sampling and click on the box for Use the same Sequence of Random Numbers" and pick any value for the seed ***NOTE this option will work for only the first simulation after opening CB Therefore first close out of CB then reopen CB and the spreadsheet and set the seed in order to test this option

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C.2.1 VIEWING RESULTS

When a simulation completes, Crystal Ball® will display results of the forecasts automatically, unless this feature is disabled If results are not displayed, choose "Run/Forecast Windows/Open all Forecasts" Crystal Ball® provides a variety of automated output, including graphs of the forecast cells (both the probability density function and cumulative distribution function views), a slider button on the graphs to obtain different percentile estimates, and summary statistics tables with the mean, SD and selected percentiles If Crystal Ball's® output does not provide the desired summary, the raw data from each iteration can be exported to a new Excel sheet ("Run/Export Data"), where a separate data analysis can be performed

C.2.2 STABILITY OF THE OUTPUT DISTRIBUTIONS

The goal of a Monte Carlo simulation is to provide a reasonable approximation of the output distribution, given a set of input distributions and an algebraic equation for risk or RSAL Different numbers of iterations (referred to by Crystal Ball® as trials) may be needed, depending on the characteristics of the input distributions, the form of the equation, and the statistics of interest in the output distribution In general, statistics nearer to the tails of the output distribution (e g , 5th or 95th percentiles) are less stable than statistics that describe the central tendency (e g , AM, 50th percentile) For the risk equations and distributions used in this analysis, sufficient stability can be obtained with 10,000 iterations Examples are given for the 1st and 5th percentiles of the distribution of RSALs for Am-241 in Figure C-9 One SD differs from the mean by only 2% for the 5th percentile and 5% for the 1st percentile based on 10 repeated simulations

C.2.3 REPRODUCING RESULTS EXACTLY

Sometimes it may be desirable to run a simulation that can be reproduced exactly This is a useful feature for regulatory review or QA/QC of probabilistic models, for example The following settings would need to be reported in order to reproduce simulation results exactly worksheet, software used, forecast cell, number of trials of the Monte Carlo simulation, random number seed, and sampling type (i e , Monte Carlo or Latin Hypercube) This feature was not employed for the simulation results reported in this report However, each of the worksheets do allow for this feature to be activated by selecting the "Run/Run Preferences" option in Crystal Ball®

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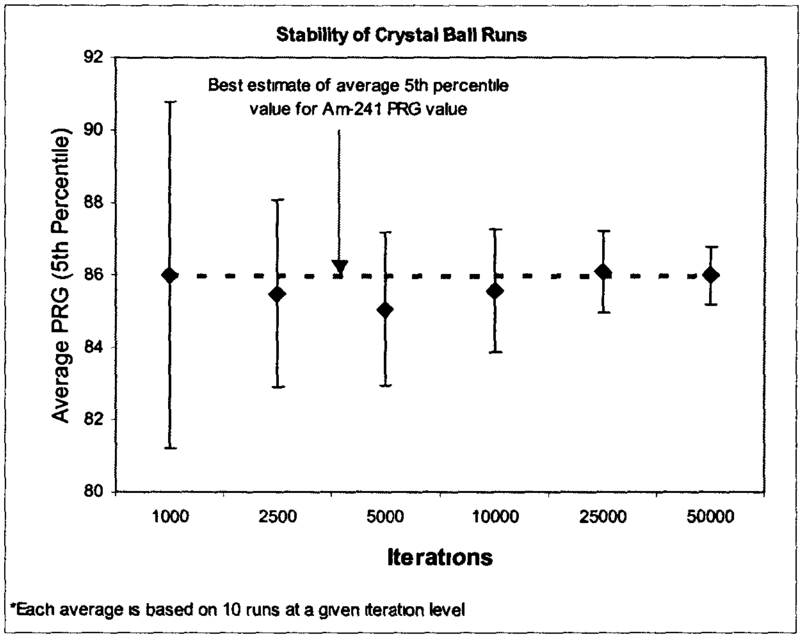

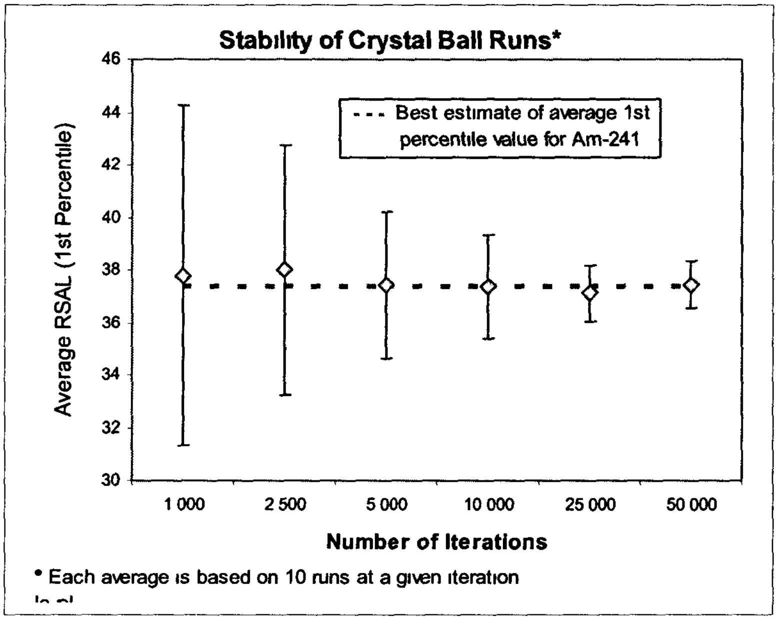

Figure C-4 Example of results of stability evaluations for Monte Carlo simulations using the RSAL for Am-241 and a Target Risk of $1x10^{-6}$ as an example The top graph illustrates the mean and standard deviation at the 5[th] percentile RSAL for n = 10 simulations for different numbers of iterations, with the "best estimate" equal to the mean for 50,000 iterations The bottom graph illustrates the same information but for the 1[st] percentile RSAL

Appendix D
Complete RESRAD Input Parameters for Dose Calculations

Computer modeling of environmental radiation exposure involves considerable simplification, mathematically, of a complex system This simplification can be justified—if it can be demonstrated that the computer model gives similar results to other accepted models, or that it can be verified to accurately or at least, conservatively predict results that can be measured in real environmental systems The RESRAD computer model has the advantages of being easy to use, well documented, and successfully tested against other models and against several real systems (Yu et al , 2001, Chapter 5) The power of the RESRAD 6 0 model resides not only in its extensive libraries of radionuclide data, dose conversion factors, and default values for parameters, but also in its user friendly interface and ability to handle parameters input as distributions RESRAD 6 0 also can be used to run Monte Carlo simulations For all its impressive features, RESRAD 6 0 is mathematically a very simple model, especially for the pathway calculations that are relevant at Rocky Flats The degree of simplicity inherent in RESRAD is the result of the simplifying assumptions about the environmental system modeled, and these assumptions, in turn, affect the degree of detail in scenario features and parameter values that can be addressed by RESRAD

The primary simplifications inherent in RESRAD include the following

- The contaminated zone is circular in shape with the receptor in the center, but can be modified by a user specified shape factor

- The residual contamination is of uniform concentration (highest value less than three times the mean value, lowest greater than one-third the mean value) This is an appropriate and even conservative assumption for a site that has been cleaned up to the RSAL value

- For areas of contamination greater than 1,000 m^2 (20,000 m^2 for meat and milk) all pathways except the inhalation pathway are independent of area (saturated) Because of this, and the assumption of uniform contamination, specific location of a receptor on a large cleaned up site (like Rocky Flats in the future) would be unimportant, since the exposure rate would be fairly uniform over the whole site

- For the inhalation pathway, a simple "box model", modified by an area and wind speed dependent dilution factor is assumed While this would be considered an inappropriate tool for short-term transport modeling, it has been shown to be adequate for approximating dose due to average exposure conditions over one year periods Under such circumstances the fluctuations in wind direction tend to average out, and the receptor is exposed to contaminated dust at close to the value of average mass loading which is the input parameter required by the model

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- For the inhalation pathway, the value of annual average mass loading is assumed to be present as respirable particles only (one micrometer activity median aerodynamic diameter (AMAD)) This is generally a conservative assumption, since the use of site-specific data (PM-10 or TSP) as a surrogate for one micrometer particulates overestimates the inhalation contribution to dose

- For soil ingestion rate and inhalation rate, RESRAD assumes a uniform rate of intake over the entire annual period modeled The soil ingestion rate must be input as total grams per year, and inhalation rate as total cubic meters per year Several of the scenario features in the risk modeling approach assume non-uniform rates of soil ingestion and inhalation during the course of a day, while on the site For example, the open space users (both adult and child) are assumed to ingest 50% of the default daily soil value during each 2 5-hour visit to the site, and to breathe at a higher than average rate Likewise, there are non-uniform rate assumptions in the soil ingestion rates of the Wildlife Refuge Worker and Office Worker scenarios The constraints of RESRAD are incorporated by assigning parameters for contaminated fractions of soil ingestion and air inhalation rates that are consistent with the risk approach, i e , the higher rates are apportioned as if they were uniform over the course of the entire year This results in artificially inflated input parameters that appear to represent unrealistically high total soil ingestion quantities for the wildlife worker, office worker, and open space users, and what appear to be unrealistically high total air volumes inhaled for the open space users

Table D-1 summarizes the full list of pathways and input parameter values that were used for each scenario modeled using RESRAD 6 0 with a 25 mrem/yr dose limit Scenarios typically differ from one another in terms of only a few parameters (see, for example, breathing rates, indoor/outdoor time fractions, soil and plant ingestion rates, etc) This is because most of the input parameters are physical features of the site being evaluated and are usually the same for all scenarios

The RESRAD default parameters and values used in the 1996 computation of RSALS for the residential scenario are also displayed in Table D-1 Note that the 1996 computation used an earlier version of RESRAD which contained a differently formulated "area correction factor" to adjust the inhalation pathway dose for dilution, and computed RSALS against 85 and 15 mrem/yr dose limits, so the earlier results are not directly comparable to the results of this task

The pathway and parameter data are presented in the order in which RESRAD prompts the user for inputs Most of the information in Table D-1 is straightforward, however, several conventions warrant explanation In the pathway section, the terms "active" and "suppressed" refer to whether the pathway calculation is turned on or off, respectively, a feature of RESRAD that makes it adaptable to a wide variety of situations

The term "not used" appears throughout the table This term is applied in some situations when an option is not applicable (for example Time for Calculations) In other situations it is applied automatically when the given parameter is requested but the pathway is turned off In some

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cases an input parameter value and "not used" appear together In these cases, the value of the input parameter would be as specified if the pathway was turned on

For parameters that are input as fixed values, a single number is given For parameters that are input to RESRAD 6 0 as distributions, the convention is to specify the "base value (type of distribution, parameters that describe the distribution)" in bold type For example, inhalation rate for rural resident (adult) is presented as 8,400 (log norm-N 8 657, 0 237) This means the first number, 8,400, signifies the point estimate value for this parameter selected by the working group The data in parentheses are information about the distribution that the user is prompted to provide as input parameters for RESRAD

RESRAD 6 0 permits the use of "continuous linear" parameter values, limited to eight total data pairs for any distributed parameter, to enable the use of empirical data What is the significance of this compared to other parameters? For the two distributions for mass loading (for inhalation and for foliar deposition) designated as "PDF #1" and "PDF #2", the values of the eight data points used to define each distribution are presented at the bottom of Table D-1

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Table D-1. Input parameters for all scenarios

RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Pathways									
External gamma		active	active	active	active	active	active	active	active
Inhalation		active	active	active	active	active	active	active	active
Plant ingestion		active	active	active	active	suppressed	suppressed	suppressed	suppressed
Meat ingestion		active	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed
Milk ingestion		active	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed
Aquatic foods		active	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed
Drinking water		active	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed
Soil ingestion		active	active	active	active	active	active	active	active
Radon		active	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed	suppressed
Initial Principal Radionuclide									
Activity in Contaminated Zone	pCi/g		Am-241	100	100	100	100	100	100
	pCi/g		Pu-238						
	pCi/g		Pu-239	100	100	100	100	100	100
	pCi/g		Pu-240						
	pCi/g		Pu-241						
	pCi/g		Pu-242						
Basic Radiation Dose Limit	mrem/y	25	15	25	25	25	25	25	25
Time for calculations	y	1	0 2	1	1	1	1	1	1
Time for calculations	y	3	1	3	3	3	3	3	3
Time for calculations	y	10	5	10	10	10	10	10	10
Time for calculations	y	30	not used	30	30	30	30	30	30
Time for calculations	y	100	not used	100	100	100	100	100	100
Time for calculations	y	300	not used	300	300	300	300	300	300
Time for calculations	y	1,000	not used	1,000	1,000	1,000	1,000	1,000	1,000
Time for calculations	y	not used	not used	not used	not used	not used	not used	not used	not used
Time for calculations	y	not used	not used	not used	not used	not used	not used	not used	not used

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Occupancy, Inhalation, and External Gamma									
Inhalation Rate	m^3/y	8,400	7,000	8,400 (log norm-N 8 657, 0 237)	5,256 (log norm-N 8 084, 0 305)	14,000 (Beta 9,636, 17,560, 1 79, 3 06)	9,636	20,000	14,000
Mass Loading for Inhalation	g/m^3	0 0001	0 000026	0 000067 (PDF 1)	0 000067 (PDF 1)	0 000067 (PDF 1)	0 000067	0 000067	0 000067
Exposure duration	y	30	30	30 not used	30 not used	30 not used	30 not used	30 not used	30 not used
Indoor Dust Filtration Factor		0 4	1	0 7	0 7	0 7	0 4	0 7	0 7
External Gamma Shielding Factor		0 7	0 8	0 4	0 4	0 4	0 4	0 4	0 4
Indoor Time Fraction		0 5	1	0 82 (triangular 408, 545, 815)	0 82 (triangular 408, 545, 815)	0 114 (B-Norm 103, 005, 091, 114)	0 23	0	0
Outdoor Time Fraction		0 25	0	0 14 (triangular 072, 096, 144)	0 14 (triangular 072, 096, 144)	0 114(B-Norm 103, 005, 091, 114)	0	0 03	0 03
Shape factor for external gamma		1	1	1	1	1	1	1	1
Area of Contaminated Zone	m^2	10,000	40,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000	1,400,000
Thickness of Contaminated Zone	m	2	0 15	0 15	0 15	0 15	0 15	0 15	0 15
Length parallel to aquifer flow	m	100	200	200	200	200	200	200	200

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Cover and Contaminated Zone Hydrological Data									
Cover depth	m	0	not used	no cover	no cover	no cover	no cover	no cover	no cover
Density cover material	g/cm^3	1 5	not used	no cover	no cover	no cover	no cover	no cover	no cover
Cover erosion rate	m/y	0 001	not used	no cover	no cover	no cover	no cover	no cover	no cover
Density of Contaminated Zone	g/cm^3	1 5	1 8	1 7	1 7	1 7	1 7	1 7	1 7
Contaminated Zone Erosion Rate	m/y	0 001	0 0000749	0 0000749	0 0000749	0 0000749	0 0000749	0 0000749	0 0000749
Contaminated zone total porosity		0 4	0 3	0 3	0 3	0 3	0 3	0 3	0 3
Contaminated zone field capacity		0 2	0 1	0 1	0 1	0 1	0 1	0 1	0 1
Contaminated zone hydraulic conductivity	m/y	10	44 5	44 5	44 5	44 5	44 5	44 5	44 5
Contaminated Zone b parameter		5 3	10 4	10 4	10 4	10 4	10 4	10 4	10 4
Humidity in air	g/m^3	8	not used	not used	not used	not used	not used	not used	not used
Evapotranspiration Coefficient		0 5	0 253	0 253	0 253	0 253	0 253	0 253	0 253
Average Annual Wind Speed	m/s	2	2	4 2	4 2	4 2	4 2	4 2	4 2
Precipitation	m/y	1	0 381	0 381	0 381	0 381	0 381	0 381	0 381
Irrigation	m/y	0 2	1	1	1	0	0	0	0
Irrigation mode		overhead	overhead	overhead	overhead	overhead	overhead	overhead	overhead
Runoff coefficient		0 2	0 004	0 004	0 004	0 004	0 004	0 004	0 004
Watershed area	m^2	1E+06	8,280,000	8,280,000	8,280,000	8,280,000	8,280,000	8,280,000	8,280,000
Accuracy for water/soil computations		0 001	0 001	0 001	0 001	0 001	0 001	0 001	0 001

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Uncontaminated Unsaturated Zone Parameters									
Number of unsaturated Zone strata		1	1	1	1	1	1	1	1
Thickness	m	4	3	3	3	3	3	3	3
Density	g/cm^3	1 5	1 8	1 7	1 7	1 7	1 7	1 7	1 7
Total porosity		0 4	0 3	0 3	0 3	0 3	0 3	0 3	0 3
Effective porosity		0 2	0 1	0 1	0 1	0 1	0 1	0 1	0 1
Field capacity		0 2	0 1	0 1	0 1	0 1	0 1	0 1	0 1
Hydraulic conductivity	m/y	10	44 5	44 5	44 5	44 5	44 5	44 5	44 5
b parameter		5 3	10 4	10 4	10 4	10 4	10 4	10 4	10 4
Radionuclide Transport Factors									
Distribution coefficient contaminated zone	cm^3/g	-		Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800	Pu = 2,300, Am = 1,800	Pu = 2,300 Am = 1,800
Distribution coefficient unsaturated zone	cm^3/g	-		Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300, Am = 1,800	Pu = 2,300, Am = 1,800	Pu = 2,300 Am = 1,800
Distribution coefficient saturated zone	cm^3/g	-		Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300 Am = 1,800 U = 2 3	Pu = 2,300, Am = 1,800	Pu = 2,300, Am = 1,800	Pu = 2,300, Am = 1,800
Time since placement of materials	year	0		0	0	0	0	0	0
Solubility Limit	mol/l	0		0	0	0	0	0	0
Leach Rate	$year^{-1}$	0		0	0	0	0	0	0

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Saturated Zone Hydrological Data									
Density of saturated zone	g/cm^3	1 5	1 8	1 7 - not used	1 7 - not used	1 7 - not used	1 7 - not used	1 7 - not used	1 7 - not used
Saturated zone total porosity		0 4	0 3	0 3 - not used	0 3 - not used	0 3 - not used	0 3 - not used	0 3 - not used	0 3 - not used
Saturated zone effective porosity		0 2	0 1	0 1 - not used	0 1 - not used	0 1 - not used	0 1 - not used	0 1 - not used	0 1 - not used
Saturated zone field capacity		0 2	0 1	0 1 - not used	0 1 - not used	0 1 - not used	0 1 - not used	0 1 -not used	0 1 - not used
Saturated zone hydraulic conductivity	m/y	100	44 5	44 5 - not used	44 5 - not used	44 5 - not used	44 5 - not used	44 5 - not used	44 5 - not used
Saturated zone hydraulic gradient		0 02	0 15	0 15 - not used	0 15 - not used	0 15 - not used	0 15 - not used	0 15 - not used	0 15 - not used
Saturated zone b parameter		5 3	not used	10 4 - not used	10 4 - not used	10 4 - not used	10 4 - not used	10 4 - not used	10 4 - not used
Water table drop rate		0 001	0	0 - not used	0 - not used	0 - not used	0 - not used	0 - not used	0 - not used
Well pump intake depth (below water table)	m	10	10	10 - not used	10 - not used	10 - not used	10 - not used	10 - not used	10 - not used
Model nondispersion (ND) or mass-balance (MB)		ND	ND	ND - not used	ND - not used	ND - not used	ND - not used	ND - not used	ND - not used
Well pumping rate	m^3/y	250	250	250 - not used	250 - not used	250 - not used	250 - not used	250 - not used	250 - not used
Ingestion Pathway, Dietary Data									
Fruit, Vegetable and Grain Consumption	kg/y	160	40 1	85 (Log norm-N 3 566, 1 446)	42 5 (Log norm-N 2 024, 1 042)	not used	not used	not used	not used
Leafy Vegetable Consumption	kg/y	14	2 6	6 4 (Log norm-N 0 418, 1 783)	3 2 (Log norm-N -1 122, 1 775)	not used	not used	not used	not used
Milk consumption	l/y	92	not used	not used	not used	not used	not used	not used	not used

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Meat and poultry consumption	kg/y	63	not used	not used	not used	not used	not used	not used	not used
Fish consumption	kg/y	5 4	not used	not used	not used	not used	not used	not used	not used
Other seafood consumption	kg/y	0 9	not used	not used	not used	not used	not used	not used	not used
Soil Ingestion	g/y	36 5	70	36 5 (Uniform 0, 47 45)	70 (B-Log norm-N 1 912, 1 371, 1, 365)	109 5 (Uniform 0, 142 4)	54 75	175 2	350 4
Drinking water intake	l/y	510	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, drinking water		1	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, household water		1	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, livestock water		1	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, irrigation water		1	0	0	0	0	0	0	0
Contaminated fraction, aquatic food		0 5	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, plant food		-1	1	1	1	1	1	1	1
Contaminated fraction, meat		-1	not used	not used	not used	not used	not used	not used	not used
Contaminated fraction, milk		-1	not used	not used	not used	not used	not used	not used	not used
Ingestion Pathway, Nondietary Data									
Livestock fodder intake for meat	kg/day	68	not used	not used	not used	not used	not used	not used	not used
Livestock fodder intake for milk	kg/day	55	not used	not used	not used	not used	not used	not used	not used
Livestock water intake for meat	l/d	50	not used	not used	not used	not used	not used	not used	not used

RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Livestock water intake for milk	l/d	160	not used	not used	not used	not used	not used	not used	not used
Livestock intake for soil	kg/day	0 5	not used	not used	not used	not used	not used	not used	not used
Mass Loading for Foliar Deposition	g/m^3	0 0001	0 0001	0 000168 (PDF 2)	0 000168 (PDF 2)	not used	not used	not used	not used
Depth of Soil Mixing Layer	m	0 15	0 15	0 15	0 15	0 15	0 15	0 15	0 15
Depth of Roots	m	0 9	0 9	0 15	0 15	not used	not used	not used	not used
Groundwater fractional usage, drinking water		1 0	not used	not used	not used	not used	not used	not used	not used
Groundwater fractional usage, household water		1 0	not used	not used	not used	not used	not used	not used	not used
Groundwater fractional usage, livestock water		1 0	not used	not used	not used	not used	not used	not used	not used
Groundwater fractional usage, irrigation water		1 0	not used	not used	not used	not used	not used	not used	not used
Plant Factors									
Wet weight crop yield, Non-leafy	kg/m^2	0 7	0 7	0 7	0 7	not used	not used	not used	not used
Length of growing season, non-leafy	years	0 17	0 17	0 17	0 17	not used	not used	not used	not used
Translocation factor, non-leafy		0 1	0 1	0 1	0 1	not used	not used	not used	not used
Weathering removal constant	1/yr	20	20	20	20	not used	not used	not used	not used
Wet foliar interception fraction, non-leafy		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Dry foliar interception fraction, non-leafy		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Wet weight crop yield, leafy	kg/m^2	1 5	1 5	1 5	1 5	not used	not used	not used	not used

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Rural Resident (Adult)	Rural Resident (Child)	Wildlife Refuge Worker	Office Worker	Open Space User (Adult)	Open Space User (Child)
Length of growing season, leafy	years	0 25	0 25	0 25	0 25	not used	not used	not used	not used
Translocation factor, leafy		1 0	1 0	1 0	1 0	not used	not used	not used	not used
Wet foliar interception fraction, leafy		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Dry foliar interception fraction, leafy		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Wet weight crop yield, fodder	kg/m^2	1 1	1 1	1 1	1 1	not used	not used	not used	not used
Length of growing season, fodder	years	0 08	0 08	0 08	0 08	not used	not used	not used	not used
Translocation factor, fodder		1 0	1 0	1 0	1 0	not used	not used	not used	not used
Weathering removal Constant, fodder	1/yr	20	20	20	20	not used	not used	not used	not used
Wet Foliar interception fraction, fodder		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Dry foliar interception Fraction, Fodder		0 25	0 25	0 25	0 25	not used	not used	not used	not used
Storage Times Before Use Data									
Fruits, non-leafy vegetables and grain	days	14	14	14	14	not used	not used	not used	not used
Leafy vegetables	days	1	1	1	1	not used	not used	not used	not used
Milk	days	1	1	not used	not used	not used	not used	not used	not used
Meat	days	20	20	not used	not used	not used	not used	not used	not used
Fish	days	7	7	not used	not used	not used	not used	not used	not used
Crustacea and mollusks	days	7	7	not used	not used	not used	not used	not used	not used
Well water	days	1	1	not used	not used	not used	not used	not used	not used
Surface water	days	1	1	not used	not used	not used	not used	not used	not used
Livestock fodder	days	45	45	not used	not used	not used	not used	not used	not used

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Continuous Linear Distributions for Mass Loading – PDF#1 for Inhalation Pathway; PDF#2 for Ingestion Pathway through Foliar Deposition

PDF #1 ** Continuous linear **	Value	CDF
Mass loading for inhalation	10	0
	20 2	0 338
	23 1	0 788
	50 7	0 919
	58	0 944
	95 7	0 969
	109	0 994
	200	1

PDF #2** Continuous Linear **	Value	CDF
Mass loading for foliar deposition	25	0
Units are micrograms/m^3	50 5	0 338
	57 7	0 788
	127	0 919
	145	0 944
	239	0 969
	274	0 994
	500	1

CDF = cumulative distribution function, PDF – probability density function

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APPENDIX E
RESRAD RUN RESULTS PRINTOUT

A CD-ROM with this information is available upon request from the Department of Energy, Closure Project Communications Team (Anna Martinez-Barnish, 303-966-5881, anna martinez@rf doe gov or Liz Wilson, 303-966-3655, Liz liz wilson@rf doe gov)

APPENDIX F
PM-10 AIR MONITORING DATA FROM ROCKY FLATS AND THE STATE OF COLORADO

Table F-1. Rocky Flats specific data

All monitor values in micrograms per cubic meter ($\mu g/m^3$)	Year	No of 24-hr Values	1st Max of 24-hr Values	2nd Max of 24-hr Values	3rd Max of 24-hr Values	4th Max of 24-hr Values	Annual Mean
Location							
X-1							
	1995	57	31	25	22	21	9 7
	1996	60	31	30	28	23	11 7
	1997	58	25	23	22	18	9 4
	1998	59	33	26	20	20	10 7
	1999	55	25	25	19	19	10 1
	2000	35	30	27	24	21	11 3
		60	33	30	28	23	11 7
X-2							
	1995	59	34	26	24	24	11 5
	1996	60	32	29	28	28	13
	1997	58	25	23	22	19	10 7
	1998	61	33	27	21	21	12
	1999	57	29	24	23	23	11 3
	2000	60	29	26	25	25	12 8
		61	34	29	28	28	13
X-3							
	1995	54	87	57	46	39	16 6
	1996	59	32	28	26	26	13 1
	1997	61	25	24	21	20	10 6
	1998	59	33	27	25	21	12 2
	1999	53	47	28	26	21	11 6
	2000	61	28	24	24	22	12 5
		61	87	57	46	39	16 6
X-4							
	1995	55	34	26	25	21	11
	1996	56	36	29	28	25	13 7
	1997	59	23	20	19	18	10 1
	1998	60	33	25	21	21	11 2
	1999	52	26	24	21	18	9 7
	2000	60	27	24	23	22	11 7
		60	36	29	28	25	13 7
X-5							
	1995	57	37	31	28	25	1
	1996	60	41	39	33	32	1
	1997	57	26	23	21	21	1
	1998	56	33	26	23	23	1
	1999	53	31	29	26	23	1
	2000	55	27	26	25	24	
		60	41	39	33	32	1

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Table F-2 Colorado PM-10 Data from EPA's AIRS Database (U S EPA, 2001)

(Monday, 28-Jun-1999 at 6 4 20 PM (USA Eastern time zone)

No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
359	179	142	135	114	1	1	38 3	1993		Adams	CO
347	122	107	99	87	0	0	35 9	1994		Adams	CO
344	99	97	88	88	0	0	33 1	1995		Adams	CO
350	98	96	90	82	0	0	33 6	1996		Adams	CO
345	98	98	96	94	0	0	34 8	1997		Adams	CO
344	118	99	93	86	0	0	36 1	1998		Adams	CO
61	73	72	70	68	0	0	25 6	1993	Northglenn	Adams	CO
59	86	40	39	38	0	0	23 5	1994	Northglenn	Adams	CO
48	41	37	36	34	0	0	21	1995	Northglenn	Adams	CO
148	82	73	68	67	0	0	26 5	1993	Brighton	Adams	CO
160	68	61	55	50	0	0	22 5	1994	Brighton	Adams	CO
174	101	84	46	46	0	0	20 5	1995	Brighton	Adams	CO
147	57	54	52	48	0	0	23 3	1996	Brighton	Adams	CO
112	86	71	58	54	0	0	23 3	1997	Brighton	Adams	CO
114	64	55	51	47	0	0	21 2	1998	Brighton	Adams	CO
114	83	77	76	75	0	0	26 9	1993		Adams	CO
114	90	53	52	48	0	0	23 6	1994		Adams	CO
113	73	46	42	40	0	0	21	1995		Adams	CO
111	59	57	48	47	0	0	21	1996		Adams	CO
128	60	46	44	44	0	0	21 8	1997		Adams	CO
58	40	39	37	37	0	0	21 9	1998		Adams	CO
351	80	61	60	52	0	0	17 7	1993		Adams	CO
351	54	51	50	47	0	0	17 1	1994		Adams	CO
301	55	44	36	35	0	0	16 5	1995		Adams	CO
340	59	58	46	44	0	0	19 4	1996		Adams	CO
265	59	53	45	45	0	0	17 2	1997		Adams	CO
326	62	56	50	45	0	0	19 3	1998		Adams	CO
342	99	69	68	64	0	0	24 7	1993	Alamosa	Alamosa	CO
345	88	83	71	68	0	0	22 9	1994	Alamosa	Alamosa	CO
350	125	86	79	72	0	0	22 4	1995	Alamosa	Alamosa	CO
309	127	92	91	69	0	0	21 3	1996	Alamosa	Alamosa	CO
332	144	113	110	93	0	0	21 6	1997	Alamosa	Alamosa	CO
333	101	88	81	72	0	0	22 9	1998	Alamosa	Alamosa	CO
61	98	98	75	65	0	0	29 4	1993	Englewood	Arapahoe	CO
59	61	60	54	49	0	0	24 3	1994	Englewood	Arapahoe	CO
14	43	33	31	31	0	0	24 9	1995	Englewood	Arapahoe	CO
339	126	125	124	113	0	0	43 5	1993		Archuleta	CO
346	262	258	110	109	2	2	41 1	1994		Archuleta	CO
335	98	97	83	80	0	0	31 7	1995		Archuleta	CO
351	85	85	78	77	0	0	32	1996		Archuleta	CO
339	120	96	89	85	0	0	29 2	1997		Archuleta	CO
335	66	66	64	61	0	0	27 2	1998		Archuleta	CO
55	75	65	61	52	0	0	23 5	1993	Boulder	Boulder	CO
55	37	35	32	32	0	0	16 9	1994	Boulder	Boulder	CO
54	35	29	23	22	0	0	13 1	1995	Boulder	Boulder	CO
59	41	31	28	26	0	0	15 8	1996	Boulder	Boulder	CO
43	28	27	24	24	0	0	15 2	1997	Boulder	Boulder	CO
334	98	81	72	66	0	0	25	1993	Longmont	Boulder	CO
330	72	58	51	49	0	0	21	1994	Longmont	Boulder	CO
324	91	61	56	49	0	0	19 3	1995	Longmont	Boulder	CO
338	66	59	56	47	0	0	18 6	1996	Longmont	Boulder	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
191	44	41	34	34	0	0	18	1997	Longmont	Boulder	CO
103	50	38	37	33	0	0	18 6	1998	Longmont	Boulder	CO
4	35	24	20	16	0	0	23 8	1994	Boulder	Boulder	CO
58	51	45	43	41	0	0	19 5	1995	Boulder	Boulder	CO
53	39	35	31	30	0	0	19 6	1996	Boulder	Boulder	CO
55	43	42	34	32	0	0	20 9	1997	Boulder	Boulder	CO
98	47	45	44	42	0	0	24 2	1998	Boulder	Boulder	CO
16	30	29	23	22	0	0	16 4	1998		Boulder	CO
109	100	86	56	56	0	0	27 8	1993	Delta	Delta	CO
127	77	70	66	64	0	0	29 5	1993	Delta	Delta	CO
329	148	105	105	105	0	0	31 5	1994	Delta	Delta	CO
342	70	69	63	63	0	0	24 4	1995	Delta	Delta	CO
340	71	67	63	60	0	0	25 6	1996	Delta	Delta	CO
202	104	55	50	50	0	0	23 1	1997	Delta	Delta	CO
50	64	40	39	38	0	0	22 8	1998	Delta	Delta	CO
46	27	24	24	23	0	0	15 9	1997		Delta	CO
59	45	35	35	32	0	0	17 6	1998		Delta	CO
8	59	28	23	20	0	0	24 4	1996		Delta	CO
51	90	78	65	53	0	0	26 9	1997		Delta	CO
53	77	68	64	46	0	0	24 8	1998		Delta	CO
72	109	101	87	87	0	0	38 9	1993	Denver	Denver	CO
83	102	89	77	69	0	0	33 1	1994	Denver	Denver	CO
59	52	50	48	44	0	0	27 9	1995	Denver	Denver	CO
56	59	54	44	43	0	0	28 1	1996	Denver	Denver	CO
89	67	66	64	62	0	0	26 4	1997	Denver	Denver	CO
53	48	47	44	43	0	0	26 7	1998	Denver	Denver	CO
60	111	103	93	91	0	0	40 5	1993	Denver	Denver	CO
57	96	73	65	63	0	0	34 9	1994	Denver	Denver	CO
57	57	57	49	46	0	0	28 7	1995	Denver	Denver	CO
59	58	50	44	43	0	0	28 3	1996	Denver	Denver	CO
59	66	66	64	62	0	0	26 3	1997	Denver	Denver	CO
52	60	51	49	49	0	0	28 2	1998	Denver	Denver	CO
343	162	122	112	108	1	1	31 8	1993	Denver	Denver	CO
342	110	104	99	88	0	0	28 3	1994	Denver	Denver	CO
337	75	65	56	53	0	0	21 1	1995	Denver	Denver	CO
338	74	67	57	56	0	0	20 4	1996	Denver	Denver	CO
242	86	71	70	67	0	0	23 1	1997	Denver	Denver	CO
361	108	81	79	74	0	0	30 9	1998	Denver	Denver	CO
58	111	110	103	82	0	0	38 8	1993	Denver	Denver	CO
58	82	70	69	61	0	0	31	1994	Denver	Denver	CO
60	44	42	40	40	0	0	25 2	1995	Denver	Denver	CO
60	56	53	53	49	0	0	27 8	1996	Denver	Denver	CO
58	92	91	84	62	0	0	28 5	1997	Denver	Denver	CO
58	73	66	59	51	0	0	28 9	1998	Denver	Denver	CO
62	117	111	104	84	0	0	39	1993	Denver	Denver	CO
57	79	71	68	64	0	0	32 6	1994	Denver	Denver	CO
59	57	45	44	41	0	0	26 9	1995	Denver	Denver	CO
61	63	53	51	48	0	0	27 7	1996	Denver	Denver	CO
59	94	93	89	62	0	0	28 9	1997	Denver	Denver	CO
55	71	69	54	47	0	0	27 1	1998	Denver	Denver	CO
336	161	119	106	100	1	1	29 4	1993	Denver	Denver	CO
335	74	72	72	71	0	0	25 4	1994	Denver	Denver	CO
350	91	80	56	50	0	0	21 4	1995	Denver	Denver	CO
345	81	70	66	66	0	0	22 8	1996	Denver	Denver	CO
348	68	66	61	60	0	0	21 8	1997	Denver	Denver	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
300	77	75	71	69	0	0	29 5	1998	Denver	Denver	CO
56	68	49	41	37	0	0	19	1993	Castle Rock	Douglas	CO
52	33	27	26	25	0	0	15 6	1994	Castle Rock	Douglas	CO
46	34	32	30	29	0	0	15 3	1995	Castle Rock	Douglas	CO
48	28	26	25	23	0	0	15 1	1996	Castle Rock	Douglas	CO
48	54	54	53	46	0	0	20 9	1997	Castle Rock	Douglas	CO
46	51	47	35	32	0	0	16 1	1998	Castle Rock	Douglas	CO
140	100	80	52	52	0	0	21	1993		Eagle	CO
130	43	38	38	36	0	0	16 7	1994		Eagle	CO
142	40	39	33	29	0	0	16 5	1995		Eagle	CO
99	77	52	43	39	0	0	17 5	1996		Eagle	CO
41	44	25	22	20	0	0	12 9	1997		Eagle	CO
43	94	46	27	20	0	0	15 8	1998		Eagle	CO
352	163	113	108	102	1	1	26 9	1993	Colorado Springs	El Paso	CO
112	50	47	43	42	0	0	20	1998	Colorado Springs	El Paso	CO
350	102	90	88	63	0	0	23	1994	Colorado Springs	El Paso	CO
349	84	72	69	65	0	0	21 1	1995	Colorado Springs	El Paso	CO
208	97	79	78	68	0	0	22 9	1997	Colorado	El Paso	CO
353	93	76	76	72	0	0	21	1996	Colorado Springs	El Paso	CO
61	58	52	48	39	0	0	22 9	1993	Colorado Springs	El Paso	CO
61	58	52	39	36	0	0	19 6	1997	Colorado Springs	El Paso	CO
58	37	36	36	36	0	0	21 7	1998	Colorado Springs	El Paso	CO
61	28	28	27	27	0	0	18 3	1996	Colorado Springs	El Paso	CO
60	47	43	40	37	0	0	21 1	1994	Colorado Springs	El Paso	CO
54	30	29	29	28	0	0	18 7	1995	Colorado Springs	El Paso	CO
61	67	61	56	52	0	0	29 9	1993	Colorado Springs	El Paso	CO
59	59	55	47	46	0	0	24 8	1995	Colorado Springs	El Paso	CO
61	50	49	43	42	0	0	23 6	1997	Colorado Springs	El Paso	CO
61	47	47	41	41	0	0	24	1998	Colorado Springs	El Paso	CO
61	65	51	42	37	0	0	24 9	1996	Colorado Springs	El Paso	CO
60	87	63	51	50	0	0	29 2	1994	Colorado Springs	El Paso	CO
57	62	54	49	46	0	0	26 8	1995	Colorado Springs	El Paso	CO
61	67	47	42	40	0	0	26	1996	Colorado Springs	El Paso	CO
59	64	56	50	49	0	0	28 6	1994	Colorado Springs	El Paso	CO
60	67	59	53	51	0	0	29 2	1993	Colorado Springs	El Paso	CO
61	51	49	46	43	0	0	23 8	1997	Colorado Springs	El Paso	CO
60	47	46	44	43	0	0	25 5	1998	Colorado Springs	El Paso	CO
57	55	26	26	25	0	0	12 6	1993		El Paso	CO
59	42	27	26	25	0	0	12 3	1994		El Paso	CO
55	37	32	31	30	0	0	13 3	1995		El Paso	CO
59	32	31	27	26	0	0	12 1	1996		El Paso	CO
61	29	27	21	20	0	0	10 4	1997		El Paso	CO
59	32	26	25	25	0	0	12 5	1998		El Paso	CO
53	52	28	28	27	0	0	13 1	1993		El Paso	CO
57	44	28	26	25	0	0	12 3	1994		El Paso	CO
59	45	32	30	26	0	0	13 6	1995		El Paso	CO
60	48	29	27	26	0	0	12 6	1996		El Paso	CO
60	28	26	19	19	0	0	9 7	1997		El Paso	CO
55	35	30	25	24	0	0	12 8	1998		El Paso	CO
55	32	31	28	27	0	0	15 9	1993	Colorado Springs	El Paso	CO
54	33	30	29	27	0	0	16 6	1994	Colorado Springs	El Paso	CO
42	32	23	22	21	0	0	13 7	1995	Colorado Springs	El Paso	CO
49	34	29	29	28	0	0	15 5	1996	Colorado Springs	El Paso	CO
51	30	27	26	25	0	0	14 7	1997	Colorado Springs	El Paso	CO
56	36	31	29	27	0	0	16 7	1998	Colorado Springs	El Paso	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
58	33	33	30	29	0	0	17 2	1993	Colorado Springs	El Paso	CO
47	44	35	31	31	0	0	17 1	1994	Colorado Springs	El Paso	CO
45	32	25	23	22	0	0	13 8	1995	Colorado Springs	El Paso	CO
48	38	35	32	29	0	0	17 1	1996	Colorado Springs	El Paso	CO
54	30	29	28	26	0	0	15 2	1997	Colorado Springs	El Paso	CO
53	43	36	32	31	0	0	17 6	1998	Colorado Springs	El Paso	CO
58	52	40	38	37	0	0	22 6	1993		El Paso	CO
60	48	47	46	46	0	0	23 5	1994		El Paso	CO
60	52	48	46	41	0	0	22 9	1995		El Paso	CO
30	66	50	42	39	0	0	27 3	1996		El Paso	CO
60	60	36	33	33	0	0	15 8	1993		El Paso	CO
59	54	46	45	39	0	0	16 8	1994		El Paso	CO
56	32	29	28	25	0	0	12 4	1995		El Paso	CO
30	34	31	27	24	0	0	15 3	1996		El Paso	CO
54	40	37	33	29	0	0	15	1993		El Paso	CO
55	92	64	58	56	0	0	18 8	1994		El Paso	CO
59	63	56	41	39	0	0	18 2	1995		El Paso	CO
26	33	31	29	28	0	0	17 8	1996		El Paso	CO
48	78	56	53	49	0	0	30 8	1993	Colorado Springs	El Paso	CO
54	49	48	46	45	0	0	25 9	1994	Colorado Springs	El Paso	CO
49	72	57	43	41	0	0	25 2	1995	Colorado Springs	El Paso	CO
52	62	58	52	51	0	0	25 4	1996	Colorado Springs	El Paso	CO
55	42	42	41	39	0	0	22 3	1997	Colorado Springs	El Paso	CO
53	47	44	42	41	0	0	23 9	1998	Colorado Springs	El Paso	CO
339	64	61	55	53	0	0	22 9	1995	Colorado Springs	El Paso	CO
10	49	43	39	32	0	0	29	1994	Colorado Springs	El Paso	CO
339	64	61	55	53	0	0	22 9	1995	Colorado Springs	El Paso	CO
341	74	65	65	63	0	0	23 2	1996	Colorado Springs	El Paso	CO
177	48	47	44	42	0	0	21 6	1998	Colorado Springs	El Paso	CO
53	84	76	52	51	0	0	30 2	1993	Colorado Springs	El Paso	CO
57	82	53	52	49	0	0	28 1	1994	Colorado Springs	El Paso	CO
56	54	50	49	47	0	0	26 6	1995	Colorado Springs	El Paso	CO
30	70	48	37	36	0	0	27 5	1996	Colorado Springs	El Paso	CO
56	94	75	67	62	0	0	27 7	1993	Colorado Springs	El Paso	CO
54	55	50	45	45	0	0	23 6	1994	Colorado Springs	El Paso	CO
55	40	39	35	32	0	0	20	1995	Colorado Springs	El Paso	CO
54	80	49	45	42	0	0	22 2	1996	Colorado Springs	El Paso	CO
54	79	56	54	52	0	0	22 5	1997	Colorado Springs	El Paso	CO
57	37	37	36	34	0	0	20 2	1998	Colorado Springs	El Paso	CO
239	65	63	60	54	0	0	19 2	1995	Colorado Springs	El Paso	CO
137	57	55	51	46	0	0	21 5	1994	Colorado Springs	El Paso	CO
239	65	63	60	54	0	0	19 2	1995	Colorado Springs	El Paso	CO
337	84	72	65	65	0	0	20 6	1996	Colorado Springs	El Paso	CO
182	90	72	62	46	0	0	19 2	1998	Colorado Springs	El Paso	CO
52	82	58	52	51	0	0	31 1	1997	Colorado Springs	El Paso	CO
52	51	46	45	41	0	0	22 5	1997	Colorado Springs	El Paso	CO
56	39	36	35	31	0	0	18 7	1998	Colorado Springs	El Paso	CO
320	77	65	63	58	0	0	19 4	1993	Canon City	Fremont	CO
332	78	75	61	61	0	0	20 3	1994	Canon City	Fremont	CO
290	65	64	52	51	0	0	17 6	1995	Canon City	Fremont	CO
46	46	37	32	30	0	0	16 9	1996	Canon City	Fremont	CO
55	41	37	34	33	0	0	16 2	1997	Canon City	Fremont	CO
58	73	41	35	32	0	0	16 3	1998	Canon City	Fremont	CO
50	136	112	89	74	0	0	40 5	1993	Rifle	Garfield	CO
57	88	82	71	63	0	0	34 9	1994	Rifle	Garfield	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
42	73	72	60	59	0	0	32 3	1995	Rifle	Garfield	CO
46	97	78	75	65	0	0	32 7	1996	Rifle	Garfield	CO
37	65	63	53	49	0	0	29 5	1997	Rifle	Garfield	CO
59	70	57	52	42	0	0	24	1998	Rifle	Garfield	CO
51	108	82	72	56	0	0	24 6	1993	Glenwood Springs	Garfield	CO
43	58	55	49	32	0	0	22 1	1994	Glenwood Springs	Garfield	CO
56	69	66	51	44	0	0	22 4	1995	Glenwood Springs	Garfield	CO
52	66	40	35	33	0	0	19	1996	Glenwood Springs	Garfield	CO
54	45	36	32	29	0	0	16 9	1997	Glenwood Springs	Garfield	CO
47	72	65	40	39	0	0	20 3	1998	Glenwood Springs	Garfield	CO
175	97	91	91	85	0	0	31 9	1993		Gunnison	CO
168	100	96	93	91	0	0	32 2	1994		Gunnison	CO
138	116	96	91	91	0	0	31 6	1995		Gunnison	CO
60	103	82	82	63	0	0	29 6	1996		Gunnison	CO
60	110	80	79	70	0	0	34 6	1997		Gunnison	CO
114	137	109	74	71	0	0	29	1998		Gunnison	CO
24	141	91	87	76	0	0	46 7	1996		Gunnison	CO
217	228	215	203	177	4	9	51 4	1997		Gunnison	CO
323	207	149	145	142	1	1	37 9	1998		Gunnison	CO
50	76	69	61	55	0	0	27 3	1993	Arvada	Jefferson	CO
35	58	47	45	42	0	0	23 1	1994	Arvada	Jefferson	CO
60	41	36	35	34	0	0	18 2	1995	Arvada	Jefferson	CO
60	56	38	36	35	0	0	19 5	1996	Arvada	Jefferson	CO
53	70	70	64	53	0	0	21 3	1997	Arvada	Jefferson	CO
56	47	46	40	39	0	0	23 4	1998	Arvada	Jefferson	CO
58	52	40	32	26	0	0	14 3	1993		Jefferson	CO
59	24	22	20	20	0	0	12 7	1994		Jefferson	CO
57	31	25	22	21	0	0	9 7	1995		Jefferson	CO
60	31	30	28	23	0	0	11 7	1996		Jefferson	CO
58	25	23	22	18	0	0	9 4	1997		Jefferson	CO
59	37	31	24	23	0	0	12 6	1998		Jefferson	CO
61	62	45	36	30	0	0	15 1	1993		Jefferson	CO
55	26	25	23	23	0	0	13 9	1994		Jefferson	CO
59	34	26	24	24	0	0	11 5	1995		Jefferson	CO
60	32	29	28	28	0	0	13	1996		Jefferson	CO
58	25	23	22	19	0	0	10 7	1997		Jefferson	CO
61	37	32	25	24	0	0	13 9	1998		Jefferson	CO
59	62	47	34	31	0	0	15 1	1993		Jefferson	CO
59	27	25	23	23	0	0	14	1994		Jefferson	CO
57	35	26	22	22	0	0	11 3	1995		Jefferson	CO
61	33	28	28	28	0	0	13 1	1996		Jefferson	CO
60	26	22	22	19	0	0	11	1997		Jefferson	CO
61	36	32	25	24	0	0	14 1	1998		Jefferson	CO
58	67	48	35	32	0	0	15 6	1993		Jefferson	CO
58	27	27	26	26	0	0	14 3	1994		Jefferson	CO
54	87	57	46	39	0	0	16 6	1995		Jefferson	CO
59	32	28	26	26	0	0	13 1	1996		Jefferson	CO
61	25	24	21	20	0	0	10 6	1997		Jefferson	CO
59	37	32	30	25	0	0	14 3	1998		Jefferson	CO
55	34	26	25	21	0	0	11	1995		Jefferson	CO
56	36	29	28	25	0	0	13 7	1996		Jefferson	CO
59	23	20	19	18	0	0	10 1	1997		Jefferson	CO
60	37	30	25	25	0	0	13 1	1998		Jefferson	CO
57	37	31	28	25	0	0	12 3	1995		Jefferson	CO
60	41	39	33	32	0	0	14 7	1996		Jefferson	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
57	26	23	21	21	0	0	11 3	1997		Jefferson	CO
56	38	31	28	27	0	0	14 8	1998		Jefferson	CO
55	104	68	51	47	0	0	24 4	1993	Golden	Jefferson	CO
34	55	53	41	34	0	0	20 7	1994	Golden	Jefferson	CO
56	38	37	35	30	0	0	15 9	1995	Golden	Jefferson	CO
56	43	31	30	26	0	0	16	1996	Golden	Jefferson	CO
6	33	28	20	19	0	0	23 5	1997	Golden	Jefferson	CO
42	93	92	86	75	0	0	42 2	1996	Durango	La Plata	CO
163	118	106	97	96	0	0	38 4	1997	Durango	La Plata	CO
254	206	77	76	71	1	1	30 2	1998	Durango	La Plata	CO
37	39	35	26	24	0	0	16 2	1997	Durango	La Plata	CO
179	83	73	59	47	0	0	17 9	1998	Durango	La Plata	CO
61	71	57	57	44	0	0	23 5	1993	Durango	La Plata	CO
46	37	32	31	29	0	0	17 2	1994	Durango	La Plata	CO
51	41	40	33	32	0	0	17 4	1995	Durango	La Plata	CO
58	57	55	47	39	0	0	18 3	1996	Durango	La Plata	CO
160	54	45	44	43	0	0	17 9	1997	Durango	La Plata	CO
168	94	57	44	37	0	0	17 5	1998	Durango	La Plata	CO
56	62	54	49	42	0	0	22 4	1993	Fort Collins	Larimer	CO
72	51	45	42	41	0	0	21 6	1994	Fort Collins	Larimer	CO
52	57	47	45	44	0	0	22 3	1995	Fort Collins	Larimer	CO
51	61	52	38	35	0	0	20 4	1996	Fort Collins	Larimer	CO
60	40	34	34	32	0	0	15 7	1997	Fort Collins	Larimer	CO
102	34	32	32	28	0	0	16 2	1998	Fort Collins	Larimer	CO
90	74	53	49	40	0	0	21	1993		Larimer	CO
34	50	39	38	37	0	0	23 2	1994		Larimer	CO
58	51	35	32	31	0	0	21 1	1993	Fruita	Mesa	CO
57	43	42	41	39	0	0	22 1	1994	Fruita	Mesa	CO
43	35	34	31	30	0	0	20	1995	Fruita	Mesa	CO
44	36	36	33	33	0	0	17 7	1996	Fruita	Mesa	CO
55	36	36	32	30	0	0	18 4	1997	Fruita	Mesa	CO
175	67	62	61	56	0	0	25	1993	Grand Junction	Mesa	CO
171	63	54	50	50	0	0	24 3	1994	Grand Junction	Mesa	CO
148	56	46	43	42	0	0	22 3	1995	Grand Junction	Mesa	CO
166	64	63	49	44	0	0	21 9	1996	Grand Junction	Mesa	CO
113	50	48	48	46	0	0	22	1997	Grand Junction	Mesa	CO
45	51	44	41	39	0	0	22 6	1998	Grand Junction	Mesa	CO
356	60	56	55	49	0	0	21 5	1993	Grand Junction	Mesa	CO
364	55	54	54	54	0	0	21 4	1994	Grand Junction	Mesa	CO
347	49	48	46	46	0	0	21 8	1995	Grand Junction	Mesa	CO
359	50	49	45	45	0	0	20 6	1996	Grand Junction	Mesa	CO
342	60	49	46	42	0	0	19 6	1997	Grand Junction	Mesa	CO
337	55	51	47	45	0	0	19 8	1998	Grand Junction	Mesa	CO
59	62	41	39	36	0	0	23 3	1993	Grand Junction	Mesa	CO
58	54	45	45	45	0	0	22 2	1994	Grand Junction	Mesa	CO
56	41	38	33	32	0	0	18 5	1995	Grand Junction	Mesa	CO
60	40	39	38	36	0	0	19 9	1996	Grand Junction	Mesa	CO
59	43	37	35	34	0	0	17 6	1997	Grand Junction	Mesa	CO
53	71	40	33	29	0	0	20 2	1998	Grand Junction	Mesa	CO
6	41	32	31	31	0	0	27 3	1995	Montrose	Montrose	CO
58	66	60	58	52	0	0	26 7	1996	Montrose	Montrose	CO
61	65	55	48	47	0	0	24 9	1997	Montrose	Montrose	CO
38	50	49	47	46	0	0	24 8	1998	Montrose	Montrose	CO
7	81	54	52	42	0	0	41 7	1997		Montrose	CO
113	79	79	74	71	0	0	35 1	1998		Montrose	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
348	98	88	84	82	0	0	23 9	1993	Aspen	Pitkin	CO
329	88	76	75	66	0	0	22 1	1994	Aspen	Pitkin	CO
334	86	83	75	74	0	0	23 3	1995	Aspen	Pitkin	CO
331	88	66	51	51	0	0	19 4	1996	Aspen	Pitkin	CO
334	92	89	74	68	0	0	21	1997	Aspen	Pitkin	CO
340	68	64	58	56	0	0	20	1998	Aspen	Pitkin	CO
282	62	61	61	53	0	0	22 6	1998	Aspen	Pitkin	CO
89	67	66	60	60	0	0	18 3	1993	Aspen	Pitkin	CO
53	81	45	43	40	0	0	19 5	1994	Aspen	Pitkin	CO
180	77	71	70	65	0	0	23 4	1993	Lamar	Prowers	CO
156	142	112	105	90	0	0	24 9	1994	Lamar	Prowers	CO
180	132	87	77	71	0	0	24 7	1995	Lamar	Prowers	CO
340	126	80	73	70	0	0	24 3	1996	Lamar	Prowers	CO
332	101	92	88	66	0	0	23	1997	Lamar	Prowers	CO
351	137	100	98	82	0	0	26 4	1998	Lamar	Prowers	CO
360	54	54	53	47	0	0	20 8	1993	Lamar	Prowers	CO
348	79	79	73	67	0	0	22	1994	Lamar	Prowers	CO
331	147	93	88	86	0	0	22 3	1995	Lamar	Prowers	CO
243	145	65	54	54	0	0	18 3	1996	Lamar	Prowers	CO
312	110	98	55	54	0	0	17 5	1997	Lamar	Prowers	CO
323	89	86	76	63	0	0	21 4	1998	Lamar	Prowers	CO
54	52	51	43	43	0	0	26 1	1993	Pueblo	Pueblo	CO
54	63	54	53	50	0	0	29 6	1994	Pueblo	Pueblo	CO
51	100	86	56	54	0	0	26 2	1995	Pueblo	Pueblo	CO
52	59	49	48	47	0	0	25 8	1996	Pueblo	Pueblo	CO
57	88	56	56	43	0	0	26 8	1997	Pueblo	Pueblo	CO
31	51	37	33	33	0	0	21 7	1998	Pueblo	Pueblo	CO
53	60	52	49	45	0	0	24 8	1998	Pueblo	Pueblo	CO
352	158	151	139	128	1	1	32 7	1993	Steamboat Springs	Routt	CO
342	154	148	136	130	0	0	31 8	1994	Steamboat Springs	Routt	CO
343	139	135	131	123	0	0	31 7	1995	Steamboat Springs	Routt	CO
307	158	137	134	125	1	1	31 5	1996	Steamboat Springs	Routt	CO
339	117	112	99	99	0	0	28	1997	Steamboat Springs	Routt	CO
352	82	77	75	75	0	0	25 7	1998	Steamboat Springs	Routt	CO
61	109	105	97	93	0	0	29 7	1996	Steamboat Springs	Routt	CO
116	91	86	84	79	0	0	27 8	1997	Steamboat Springs	Routt	CO
168	128	126	106	96	0	0	28	1993	Steamboat Springs	Routt	CO
153	142	124	121	118	0	0	28 2	1994	Steamboat Springs	Routt	CO
145	118	114	103	97	0	0	23	1995	Steamboat Springs	Routt	CO
74	83	77	54	54	0	0	23 2	1996	Steamboat Springs	Routt	CO
330	135	126	118	117	0	0	39 4	1993		San Miguel	CO
281	153	127	123	108	0	0	33 8	1994		San Miguel	CO
273	119	103	95	90	0	0	34 8	1995		San Miguel	CO
321	107	105	101	89	0	0	25 8	1996		San Miguel	CO
297	96	80	75	74	0	0	24 9	1997		San Miguel	CO
316	70	65	65	63	0	0	23 9	1998		San Miguel	CO
19	27	24	24	22	0	0	16 3	1996		San Miguel	CO
272	82	76	75	69	0	0	26 4	1997		San Miguel	CO
362	90	72	58	57	0	0	25 5	1998		San Miguel	CO
47	44	42	41	39	0	0	17	1995		San Miguel	CO
52	130	95	92	83	0	0	24 4	1993		Summit	CO
43	126	90	84	73	0	0	24 1	1994		Summit	CO
47	97	68	52	47	0	0	18	1995		Summit	CO
40	50	26	26	23	0	0	13 4	1996		Summit	CO
58	95	75	37	32	0	0	17 1	1997		Summit	CO

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No of 24-hr Values	1st Max of 24-hr Value	2nd Max of 24-hr Value	3rd Max of 24-hr Value	4th Max of 24 hr Value	Actual # of Exceedences	Est # of Exceedences	Annual Mean	Year	City	County	State
110	125	69	67	65	0	0	19 2	1998		Summit	CO
11	67	61	44	43	0	0	34 5	1993		Summit	CO
42	82	62	59	53	0	0	27 4	1994		Summit	CO
16	76	72	47	43	0	0	32 4	1995		Summit	CO
48	78	56	49	40	0	0	24 9	1996		Summit	CO
52	62	40	38	38	0	0	18 8	1997		Summit	CO
50	47	46	44	44	0	0	21 9	1998		Summit	CO
12	139	122	83	54	0	0	57 2	1994		Teller	CO
96	306	266	214	204	6	19	51 5	1995		Teller	CO
316	235	195	158	157	4	5	39 1	1996		Teller	CO
228	135	121	120	111	0	0	39 9	1997		Teller	CO
249	139	124	120	109	0	0	41	1998		Teller	CO
150	120	99	80	76	0	0	22 6	1993	Greeley	Weld	CO
143	75	57	56	48	0	0	23 1	1994	Greeley	Weld	CO
132	60	59	51	46	0	0	19 9	1995	Greeley	Weld	CO
159	60	56	45	42	0	0	17 7	1996	Greeley	Weld	CO
114	133	56	52	46	0	0	17 8	1997	Greeley	Weld	CO
107	40	39	36	32	0	0	16 5	1998	Greeley	Weld	CO
50	110	82	73	70	0	0	30 5	1993		Weld	CO
56	89	68	53	49	0	0	27 5	1994		Weld	CO
23	53	45	39	36	0	0	21	1995		Weld	CO

*Colorado Air Quality Monitors for Particulate Matter (All Years)

* Monitor Values In Micrograms Per Cubic Meter of Air ($\mu g/m^3$)

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APPENDIX G
RESRAD RESULTS FOR THE RESIDENT RANCHER SCENARIO

The RSAL working group has committed to model the Resident Rancher scenario (both adult and child cases) as described in the RAC Independent Calculation using RESRAD 6 0, for the purpose of comparing the computational methods employed by RAC to those employed by the work group On the surface, this task appears to be straightforward—simply input the parameters described in RAC Tasks 3 and 5, (RAC, 1999, and RAC, 2000) into RESRAD 6 0 and perform the computation

However, the working group soon learned that it was not a simple matter to duplicate the inputs that RAC used for annual average air mass loading (dust in air) For the Independent Calculation, RAC computed this parameter not as a distribution, but as a series of calculations, which are combined with other parameters selected from distributions Moreover, the calculated values of mass loading which RAC created were heavily influenced by the assumptions of pre-clean-up conditions, placement of the receptor at a point of maximum air concentration, and inclusion of probabilistic impacts of a fire RAC's calculation of the mass loading parameter (for each realization) is performed by a RAC developed code that is beyond the scope of the RSAL working group to reproduce With this in mind, the working group has sought to formulate a value for the mass loading input parameter that is consistent with RAC's work

The working group used the PERL-script code developed by RAC (RAC, 2000, Appendix A) to produce a distribution of intermediate values of annual average mass loading (These are the values of mass loading that RAC input into their copy of the RESRAD code, along with samples from each of their various distributions of other physical parameters, for each realization) From the distribution of 1,000 values of mass loading calculated by the RAC algorithm, the 90th and 95th percentile values were selected The working group then selected conservative single-point estimates for the other distributed parameters, that RAC used, and calculated RSALs for plutonium and americium for the case of the adult and child resident rancher using single point estimate runs of RESRAD 6 0 Although this appears to conservatively approximate the RAC approach, it does not duplicate it In order to do so one would have to use the entire RAC code for selecting samples of each parameter distribution every time the mass loading value is computed RAC's independent calculation has already done this The approximation described above, serves as a benchmark or point of comparison of the working group's computer model with RAC's total assessment of this scenario

G.1.0 MODELING ASSUMPTIONS

All active pathways and all input parameters for the resident rancher scenario are identical to those found in the RAC Task 3 Report Inputs and Assumptions (RAC, 1999) except for substitutions of fixed values for uptake parameters and distribution coefficients, and the use of two fixed values of mass loading taken from a distribution of RAC calculated values All features of the rancher scenario are the same as modeled by RAC All exposure pathways except aquatic food and radon are active in this calculation Consistent with the RAC calculation, the contaminated fractions of drinking water, irrigation water and livestock water are all set to zero values (RAC, 2000, Appendix A)

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(1) The area of the contaminated zone is a 10 million square meter area that is uniformly contaminated to the RSAL concentration The resident is located in the center This is a conservative substitution, which is consistent with RESRAD input requirements However, based on information provided in the RSAL workshop of April, 2000, the mass loading estimates were calculated by RAC as though the resident was located at a point of maximum air concentration, not necessarily in the area of contamination The radionuclide concentration in air was also higher than would be predicted by RESRAD

(2) Both dose limits of 25 mrem per year and 15 mrem per year are modeled This permits easy comparison to other calculations in this task and to RAC's calculation These computations use the same dose conversion factors for adults and children as used by RAC (plutonium type "S" absorption, child dose conversion factors for age 10), unlike the more conservative dose conversion factors used to calculate RSALs in this assessment (plutonium type "M", child dose conversion factors for age one)

(3) RESRAD single default values of the distribution coefficients and plant, meat, and milk uptake fractions for plutonium and americium are used in lieu of the distributions used by RAC The fixed default values in RESRAD lie on the conservative side of RAC's distributions, and have little impact on the results which are dominated by the impact of high values of mass loading for inhalation

(4) Consistent with RAC's scenario, the rancher adult and child spend all of their time on the site, with times outdoors of 40% and 25%, respectively Indoor dust and gamma shielding factors are the same as used by RAC

(5) Breathing rates, and consumption rates of homegrown produce, meat, milk and drinking water (from shallow groundwater) are the same values as described in RAC's final report

(6) Single values for annual average mass loading for inhalation/foliar deposition (3,180 and 8,920 micrograms per cubic meter for the 90th and 95th percentile, respectively) are used These are derived by using the RAC mass loading subroutine to calculate a distribution of 1,000 points, followed by selection of the 90th and 95th percentile values of this distribution

(7) The sum-of-ratios method described in Chapter 5 of this assessment is applied to the single radionuclide soil guidelines calculated for plutonium and for americium by RESRAD 6 0 The assumption is made that americium is present at 15 3% of the plutonium activity across the entire site, which is consistent with americium ingrowth for weapons grade plutonium that has aged between 35 and 45 years

G.2.0 RESULTS AND DISCUSSION

Tables G-1 and G-2 summarize the values of RSALs calculated by the sum-of-ratios method for the 90th and the 95th percentile values of RAC calculated annual average mass loading of one micron particles, respectively The high values of mass loading clearly drive the dose calculation At the 90th percentile the combination of inhalation and plant ingestion dose (which

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is strongly controlled by deposition of dust on plants) account for approximately 85% of the total dose For the 95th percentile, this same combination accounts for up to 95% of the total dose

Table G-1. RSALs (pCi/g) for Resident Rancher at 90th percentile value of RAC-calculated[1] mass loading (3,180 μg/m³) Inhalation pathway contributions range from 64 to 70% of total dose For comparative purposes only

Isotope	Sum-of-Ratios RSAL			
	Adult 25 mrem/yr	**Child (age 10) 25 mrem/yr**	**Adult 15 mrem/yr**	**Child (age 10) 15 mrem/yr**
Pu	45	49	27[1]	30
Am	7	8	4	5

[1] Most comparable RSAL value to RAC Task 5 Report value

Table G-2. RSALs (pCi/g) for Resident Rancher at 95th percentile value of RAC-calculated[1] mass loading (8,920 μg/m³) Inhalation pathway contributions range from 81 to 85% of total dose For comparative purposes only

Isotope	Sum-of-Ratios RSAL			
	Adult 25 mrem/yr	**Child (age 10) 25 mrem/yr**	**Adult 15 mrem/yr**	**Child (age 10) 15 mrem/yr**
Pu	20	22	12	13
Am	3	3	2	2

[1] Most comparable RSAL value to RAC Task 5 Report value

More than one third of the annual average mass loading values calculated by RAC's subroutine exceed the highest actual measured value for PM-10 annual averages reported to the Aerometric Information Retrieval System, or AIRS (U S EPA, 2001) (268 μg/m³ in Mexicali, Baja California in 2000) and greatly exceed the National Ambient Air Quality Standard for PM-10 annual average (50 μg/m³) Specifically, the 90th and 95th percentile values of RAC's distribution, used in this calculation are 12 and 33 times higher, respectively than the highest PM-10 annual averages reported to AIRS to date It is noteworthy that PM-10 values approaching those generated by the RAC code are observed in AIRS as 24-hour averages in extreme cases, but annual average values are significantly lower by at least one order of magnitude

The RAC independently calculated RSAL is strongly dependent on the computer generated value of mass loading that is applied to capture the variability of resuspension of contaminants following a fire, and is based upon short term measurements of resuspension under conditions of mechanical disturbance at the Rocky Flats site during 1970-71 Over 90% of the RAC-predicted annual dose is due to inhalation when annual average mass loading is on the order of 3,000 micrograms per cubic meter The working group also chose to create an empirically derived distribution for this parameter Its distribution is based primarily upon measured annual average mass loading (weighted by factors to account for reasonably attributable soil-disturbance activities) and modified to account for the annual average contributions of a grassland fire Unlike the RAC approach, this input uses the RESRAD algorithms directly to calculate the resultant radionuclide content in the airborne pathway

The most comparable RSAL value for the RESRAD 6 0 Resident Rancher scenario to that calculated in RAC's Task 5 Report is the adult value for a 15 mrem/yr dose limit at the 90th percentile of RAC's mass loading distribution (the percentile used by RAC to derive their RSAL) As can be seen from Table G-1, the working group's value of 27 pCi/g for Pu agrees rather well with RAC's 35 pCi/g This agreement reconfirms that differences between the working group's dose based RSAL values and RAC's are largely due to differences in the generation of input parameters, particularly the distribution for mass loading values, and cannot be attributed to differences in computer models

Table G-3 is a complete listing of the RESRAD 6 0 parameters that were used in the adult and child resident rancher calculations

Table G-3. Complete listing of RESRAD 6 0 parameters that were used in the adult and child resident rancher calculations

RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Resident Rancher (Adult)	Resident Rancher (Child)
Pathways					
External gamma		active	active	active	active
Inhalation		active	active	active	active
Plant ingestion		active	active	active	active
Meat ingestion		active	suppressed	active	active
Milk ingestion		active	suppressed	active	active
Aquatic foods		active	suppressed	suppressed	suppressed
Drinking water		active	suppressed	active	active
Soil ingestion		active	active	active	active
Radon		active	suppressed	suppressed	suppressed
Initial Principal Radionuclide Activity in Contaminated Zone					
NOTE· For these values, see the report Action Levels for Radionuclides in Soil for the Rocky Flats Cleanup Agreement, October 31, 1996	pCi/g		Am-241	0 111	0 111
	pCi/g		Pu-238	0 0132	0 0132
	pCi/g		Pu-239	0 843	0 843
	pCi/g		Pu-240	0 157	0 157
	pCi/g		Pu-241	0 798	0 798
	pCi/g		Pu-242	7 62E-06	7 62E-06
Basic radiation dose limit	mrem/y	25	15	15 & 25	15 & 25
Time for calculations	y	1	0 2	29	29
Time for calculations	y	3	1	1029	1029
Time for calculations	y	10	5	not used	not used
Time for calculations	y	30	not used	not used	not used
Time for calculations	y	100	not used	not used	not used
Time for calculations	y	300	not used	not used	not used
Time for calculations	y	1,000	not used	not used	not used
Time for calculations	y	not used	not used	not used	not used
Time for calculations	y	not used	not used	not used	not used
Occupancy, Inhalation, and External Gamma					
Inhalation rate	m^3/y	8,400	7,000	10,800	8,600

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RESRAD 6.0 Input Parameters	**Units**	**RESRAD 6.0 Default**	**1996 Input Value**	**Resident Rancher (Adult)**	**Resident Rancher (Child)**
Mass Loading for Inhalation	g/m^3	0 0001	0 000026	0 00318(90%) & 0 008920(95%)	0 00318(90%) & 0 008920(95%)
Exposure duration	y	30	30	30 not used	30 not used
Indoor dust filtration factor		0 4	na	0 7	0 7
External gamma shielding factor		0 7	0 8	0 7	0 7
Indoor time fraction		0 5	1	0 6	0 75
Outdoor time fraction		0 25	0	0 4	0 25
Shape factor for external gamma		1	1	1	1
Area of Contaminated Zone	m^2	10,000	40,000	10,000,000	10,000,000
Thickness of contaminated zone	m	2	0 15	0 2	0 2
Length parallel to aquifer flow	m	100	200	3,000	3,000
Cover and Contaminated Zone Hydrological Data					
Cover Depth	m	0	0	no cover	no cover
Density of cover material	g/cm^3	1 5	not used	no cover	no cover
Cover erosion rate	m/y	0 001	not used	no cover	no cover
Density of contaminated zone	g/cm^3	1 5	1 8	1 8	1 8
Contaminated zone erosion rate	m/y	0 001	0 0000749	0 0000749	0 0000749
Contaminated zone total porosity		0 4	0 3	0 3	0 3
Contaminated zone field capacity		0 2	0 1	0 1	0 1
Contaminated zone hydraulic conductivity	m/y	10	44 5	44 5	44 5
Contaminated zone b parameter		5 3	10 4	10 4	10 4
Humidity in air	g/m^3	8	not used	not used	not used
Evapotranspiration coefficient		0 5	0 253	0 92	0 92
Average annual wind speed	m/s	2	not used	4 2	4 2
Precipitation	m/y	1	0 381	0 381	0 381
Irrigation	m/y	0 2	1	0	0
Irrigation mode		overhead	overhead	overhead	overhead
Runoff coefficient		0 2	0 004	0 2	0 2
Watershed area	m^2	1,000,000	8,280,000	8,280,000	8,280,000
Accuracy for water/soil computations		0 001	0 001	0 001	0 001
Uncontaminated Unsaturated Zone Parameters					
Number of unsaturated zone strata		1	1	1	1
Thickness	m	4	3	3	3
Density	g/cm^3	1 5	1 8	1 8	1 8
Total porosity		0 4	0 3	0 3	0 3
Effective porosity		0 2	0 1	0 1	0 1
Field capacity		0 2	NA	0 1	0 1
Hydraulic conductivity	m/y	10	44 5	44 5	44 5
b Parameter		5 3	10 4	10 4	10 4

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Resident Rancher (Adult)	Resident Rancher (Child)
Radionuclide Transport Factors					
Distribution coefficient contaminated zone	cm^3/g	-	See Rocky Flats Cleanup Agreement, October 31, 1996 Report	Pu = 2,000 Am = 20	Pu = 2,000 Am = 20
Distribution coefficient unsaturated zone	cm^3/g	-		Pu = 2,000 Am = 20	Pu = 2,000 Am = 20
Distribution coefficient saturated zone	cm^3/g	-		Pu = 2,000 Am = 20	Pu = 2,000 Am = 20
Time since placement of materials	year	0	na	0	0
Solubility Limit	mol/l	0	0	0	0
Leach rate	year-1	0	0	0	0
Saturated Zone Hydrological Data					
Density of saturated zone	g/cm^3	1 5	1 8	1 8	1 8
Saturated zone total porosity		0 4	0 3	0 3	0 3
Saturated zone effective porosity		0 2	0 1	0 1	0 1
Saturated zone field capacity		0 2	na	0 1	0 1
Saturated zone hydraulic conductivity	m/y	100	44 5	44 5	44 5
Saturated zone hydraulic gradient		0 02	0 15	0 15	0 15
Saturated zone b parameter		5 3	5 3	5 3	5 3
Water table drop rate		0 001	0	0	0
Well pump intake depth (below water table)	m	10	10	10	10
Model nondispersion (ND) or mass-balance (MB)		ND	ND	ND	ND
Well pumping rate	m^3/y	250	250	250	250
Ingestion Pathway, Dietary Data					
Fruit, vegetable and grain consumption	kg/y	160	40 1	190	240
Leafy vegetable consumption	kg/y	14	2 6	64	42
Milk consumption	l/y	92	not used	110	200
Meat and poultry consumption	kg/y	63	not used	95	60
Fish consumption	kg/y	5 4	not used	not used	not used
Other seafood consumption	kg/y	0 9	not used	not used	not used
Soil ingestion	g/y	36 5	70	75	75
Drinking water intake	l/y	510	not used	730	550
Contaminated fraction, drinking water		1	not used	0	0
Contaminated fraction, household water		1	not used	not used	not used
Contaminated fraction, livestock water		1	not used	0	0
Contaminated fraction, irrigation water		1	0	0	0
Contaminated fraction, aquatic food		0 5	not used	not used	not used
Contaminated fraction, plant food		-1	1	1	1

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RESRAD 6.0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Resident Rancher (Adult)	Resident Rancher (Child)
Contaminated fraction, meat		-1	not used	1	1
Contaminated fraction, milk		-1	not used	1	1
Ingestion Pathway, Nondietary Data					
Livestock fodder intake for meat	kg/day	68	not used	68	68
Livestock fodder intake for milk	kg/day	55	not used	55	55
Livestock water intake for meat	l/d	50	not used	0	0
Livestock water intake for milk	l/d	160	not used	0	0
Livestock intake for soil	kg/day	0 5	not used	0 5	0 5
Mass Loading for Foliar Deposition	g/m^3	0 0001	0 0001	0 00318(90%) 0 00892(95%)	0 00318(90%) 0 00892(95%)
Depth of soil mixing layer	m	0 15	0 15	0 03	0 03
Depth of roots	m	0 9	0 9	0 9	0 9
Groundwater fractional usage, drinking water		1	1	1	1
Groundwater fractional usage, household water		1	not used	not used	not used
Groundwater fractional usage, livestock water		1	not used	1	1
Groundwater fractional usage, irrigation water		1	not used	1	1
Plant Factors					
Wet weight crop yield, non-leafy	kg/m^2	0 7	NA	0 7	0 7
Length of growing season, non-leafy	years	0 17	NA	0 17	0 17
Translocation factor, non-leafy		0 1	NA	0 1	0 1
Weathering removal constant	1/yr	20	NA	20	20
Wet foliar Interception Fraction, non-leafy		0 25	NA	0 25	0 25
Dry foliar interception Fraction, non-leafy		0 25	NA	0 25	0 25
Wet weight crop yield, leafy	kg/m^2	1 5	NA	1 5	1 5
Length of growing season, leafy	years	0 25	NA	0 25	0 25
Translocation factor, leafy		1	NA	1	1
Wet foliar interception fraction, leafy		0 25	NA	0 25	0 25
Dry foliar Interception Fraction, leafy		0 25	NA	0 25	0 25
Wet weight crop yield, fodder	kg/m^2	1 1	NA	1 1	1 1
Length of growing season, fodder	years	0 08	NA	0 08	0 08
Translocation factor, fodder		1	NA	1	1
Weathering removal constant, fodder	1/yr	20	NA	20	20
Wet foliar interception fraction, fodder		0 25	NA	0 25	0 25
Dry Foliar interception fraction, fodder		0 25	NA	0 25	0 25

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RESRAD 6 0 Input Parameters	Units	RESRAD 6 0 Default	1996 Input Value	Resident Rancher (Adult)	Resident Rancher (Child)
Storage Times Before Use Data					
Fruits, non-leafy vegetables and grain	days	14	14	14	14
Leafy vegetables	days	1	1	1	1
Milk	days	1	not used	1	1
Meat	days	20	not used	20	20
Fish	days	7	not used	not used	not used
Crustacea and mollusks	days	7	not used	not used	not used
Well water	days	1	1	1	1
Surface water	days	1	1	1	1
Livestock fodder	days	45	not used	45	45

APPENDIX H
TORNADO PLOTS SHOWING PROBABILISTIC SENSITIVITY ANALYSIS RESULTS FOR RISK-BASED RSALS

This appendix gives a graphical summary of the sensitivity analysis associated with the probabilistic calculations for the Rural Resident and Wildlife Refuge Worker scenarios using EPA's standard risk equations A separate graphic is presented for each individual radionuclide (Am-241, Pu-239, U-234, U-235, U-238) as well as the uranium non-cancer assessment In addition, two different quantitative metrics of sensitivity are given – the Spearman Rank correlation coefficient, and the Contribution to Variance, which is calculated as the square of the rank correlations normalized so they sum to 1 0 or 100% of the variance in RSAL Therefore, a total of 20 graphs are presented (2 scenarios x 5 radionuclides x 2 statistical metrics of sensitivity)

In this type of simple correlation analysis, the correlation between the Monte Carlo model output (i e , RSAL) is compared to each input variable separately (i e , one at a time) Two types of information are of greatest interest (1) the relative magnitudes of the correlations (or contributions to variance), and (2) the direction of the correlation (positive or negative) The tornado plot is a useful graphic for presenting both types of information for all input variables simultaneously The tornado plots presented here give the abbreviated names of the input variables, sorted in descending order The length of the horizontal bar corresponds to the magnitude of the correlation, and the direction (extending to the left or right of 0 0) indicates whether the relationship is direct or inverse For example, a negative correlation between exposure duration and RSAL suggests an inverse relationship such that as exposure duration increases, the RSAL must decrease in order to remain health-protective

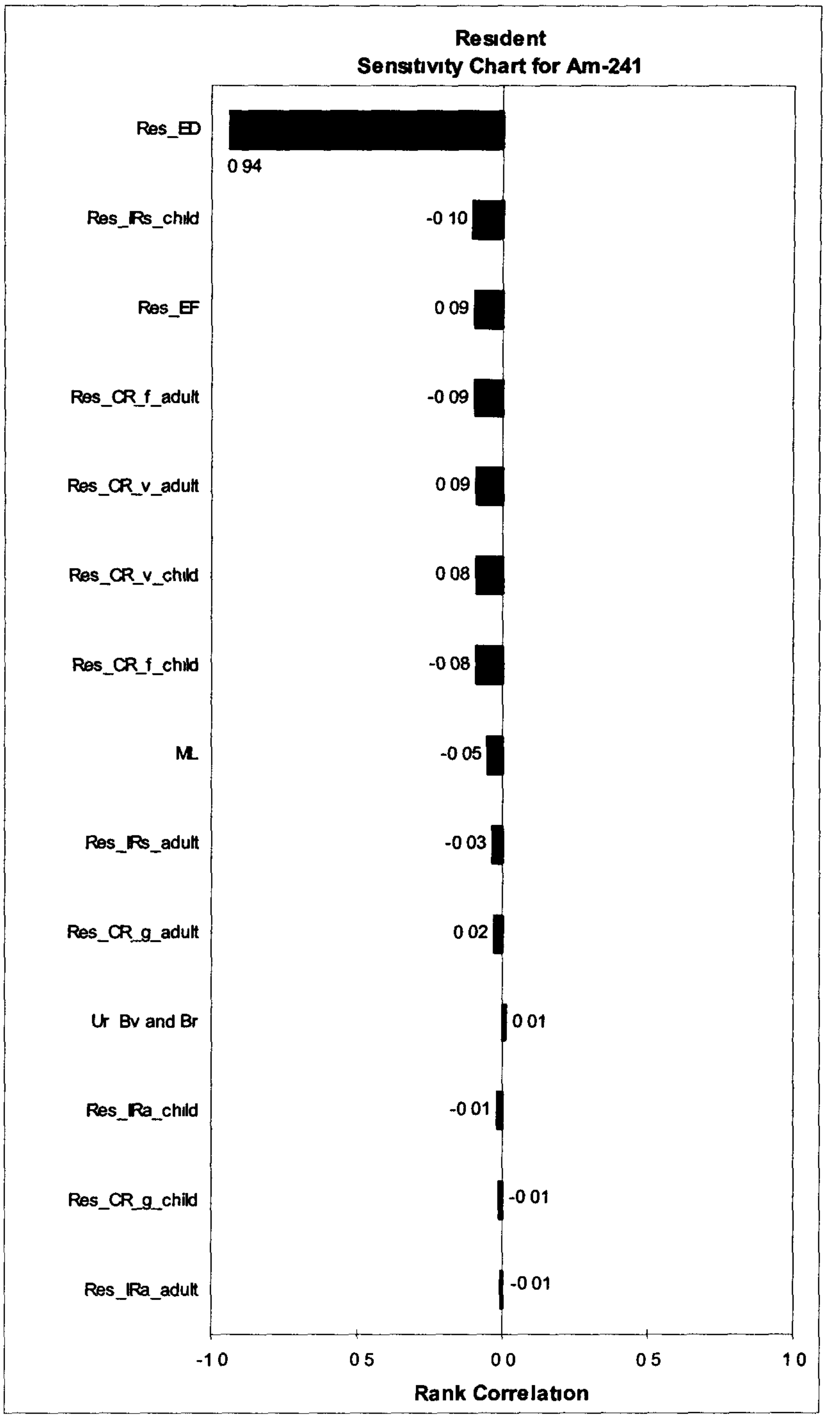

Figure H-1. Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, Am-241, rank correlations

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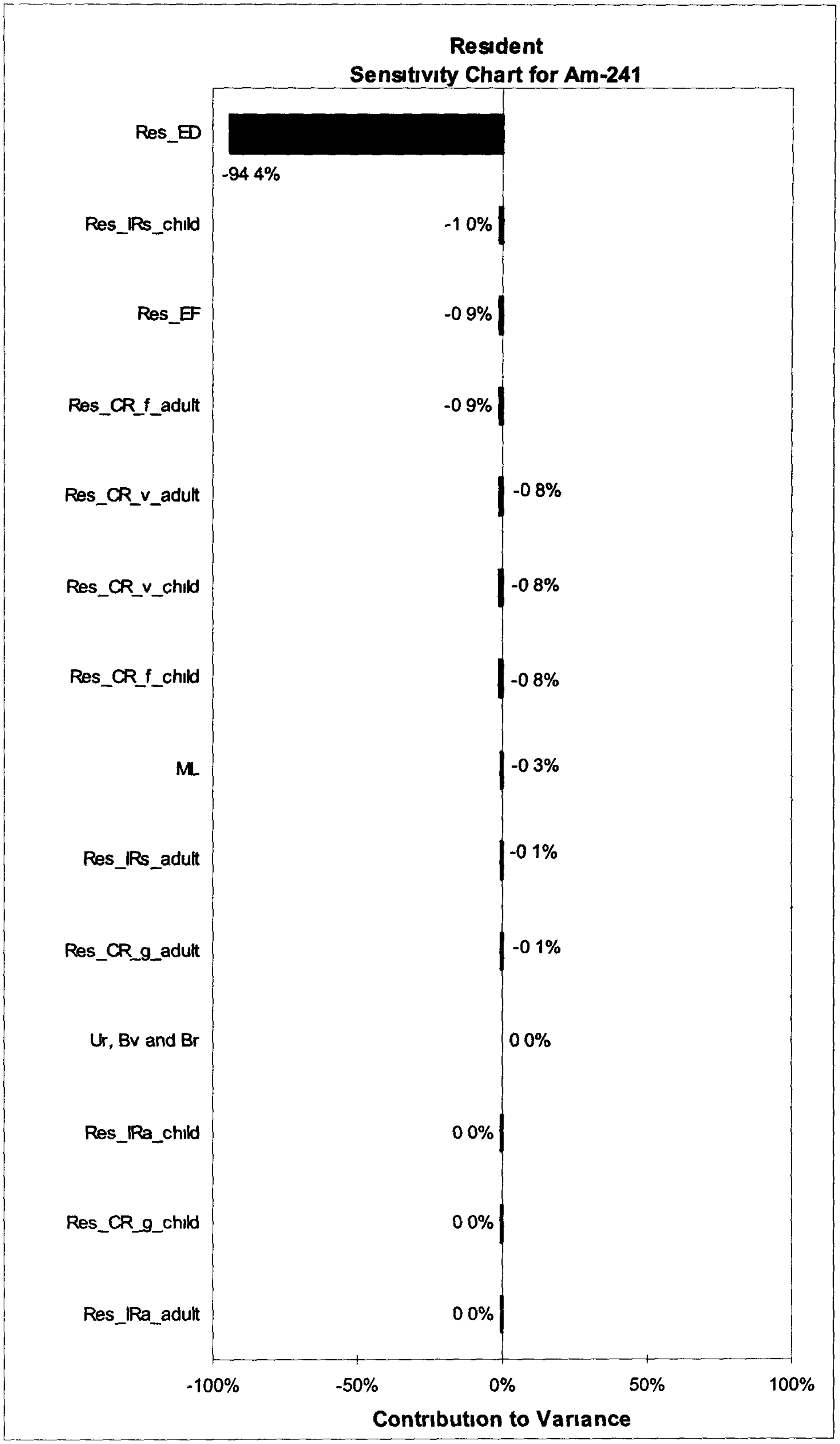

Figure H-2 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, Am-241, contribution to variance

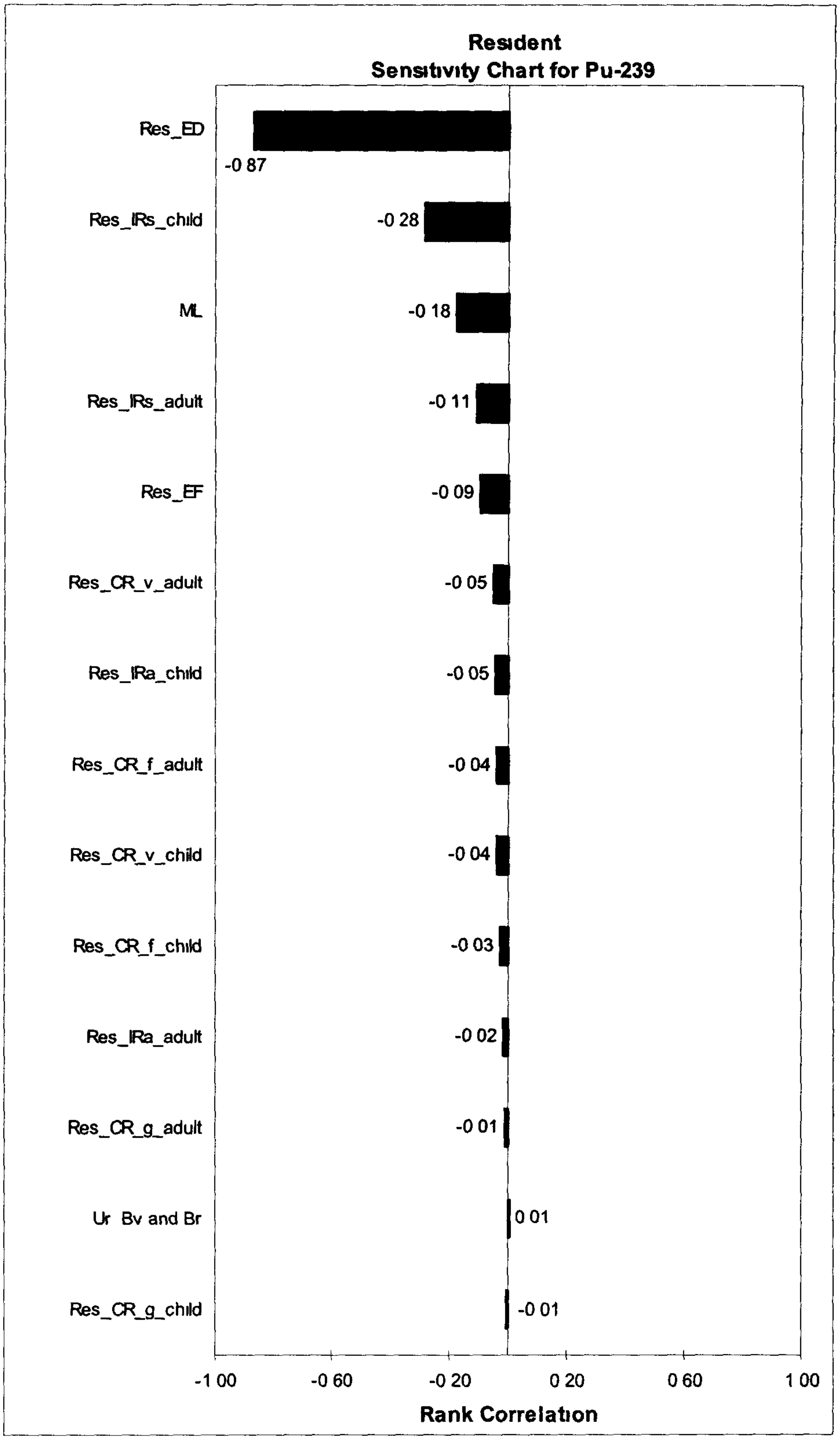

Figure H-3 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, Pu-239, rank correlation

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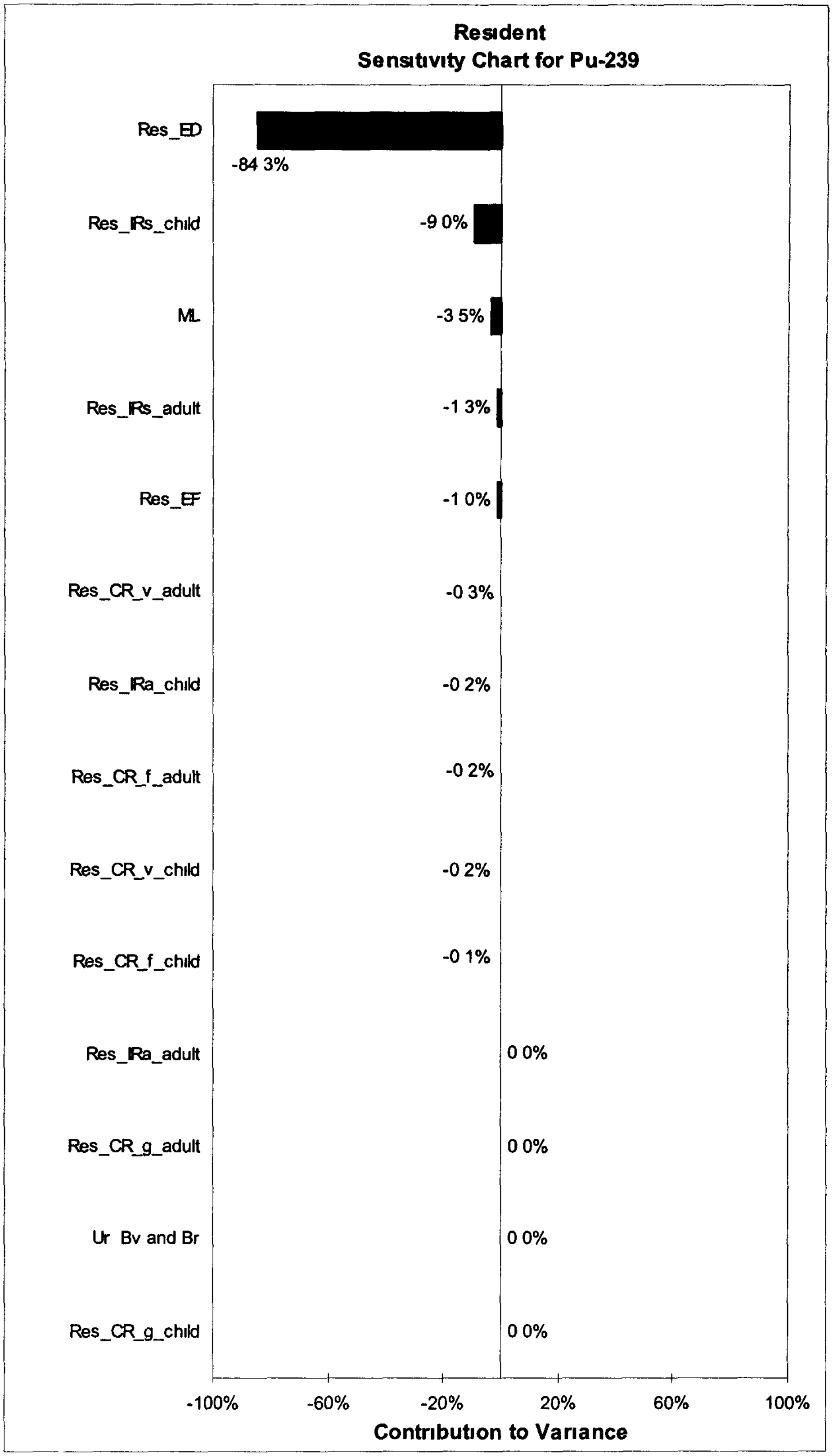

Figure H-4 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, Pu-239, contribution to variance

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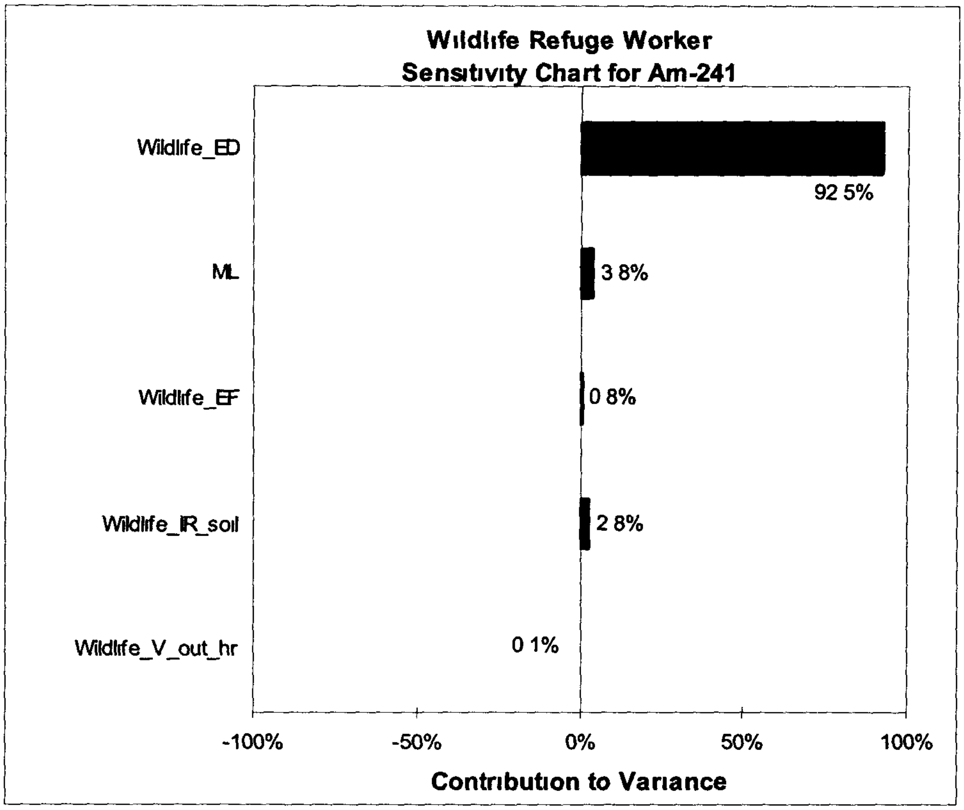


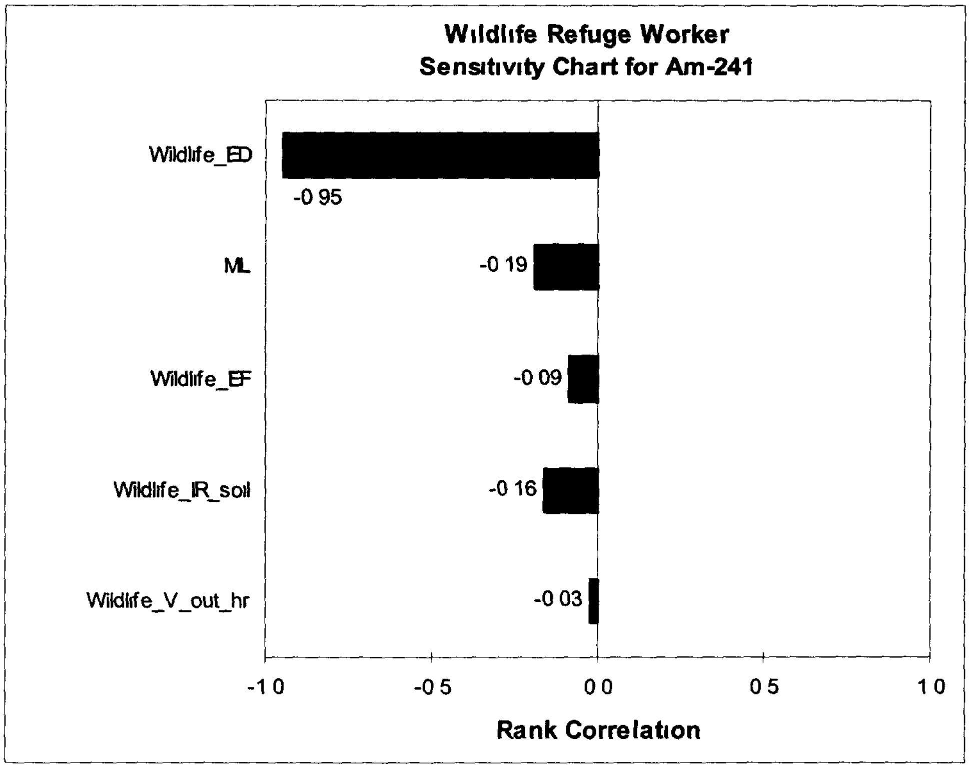
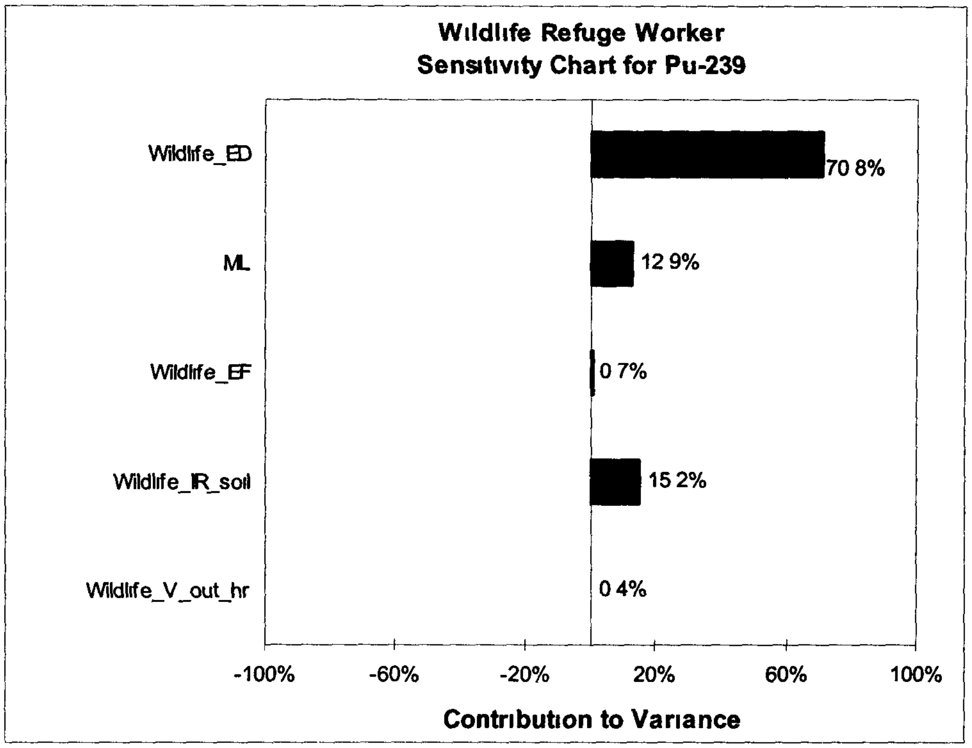


Figure H-5 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, Am-241, contribution to variance (top) and rank correlation (bottom)



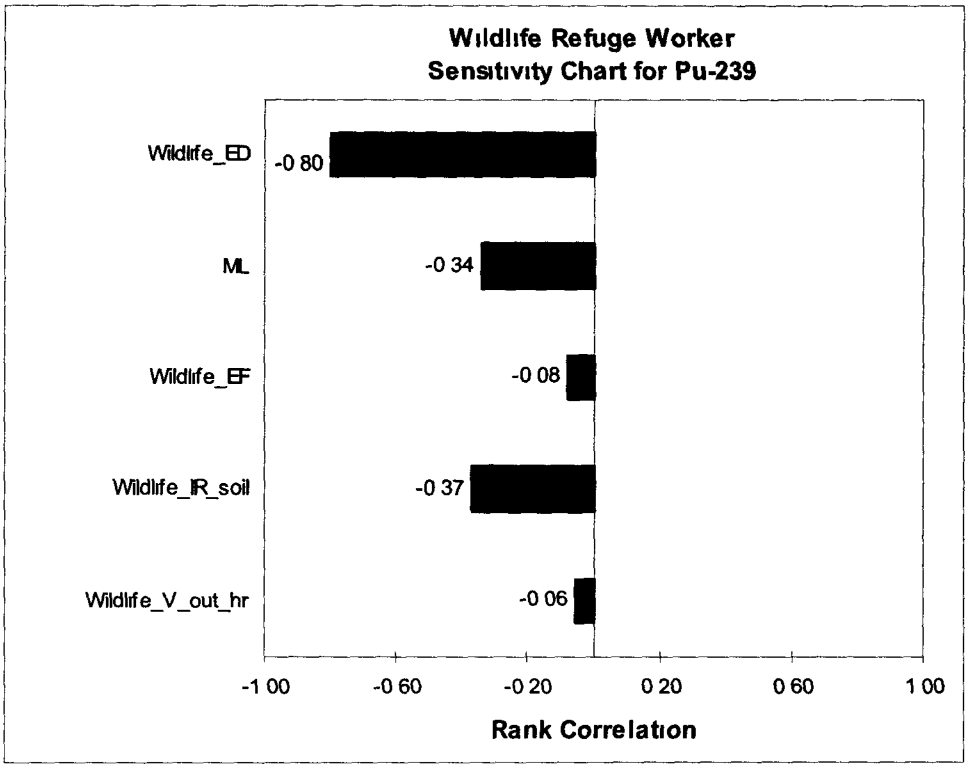


Figure H-6 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, Pu-239, contribution to variance (top) and rank correlation (bottom)

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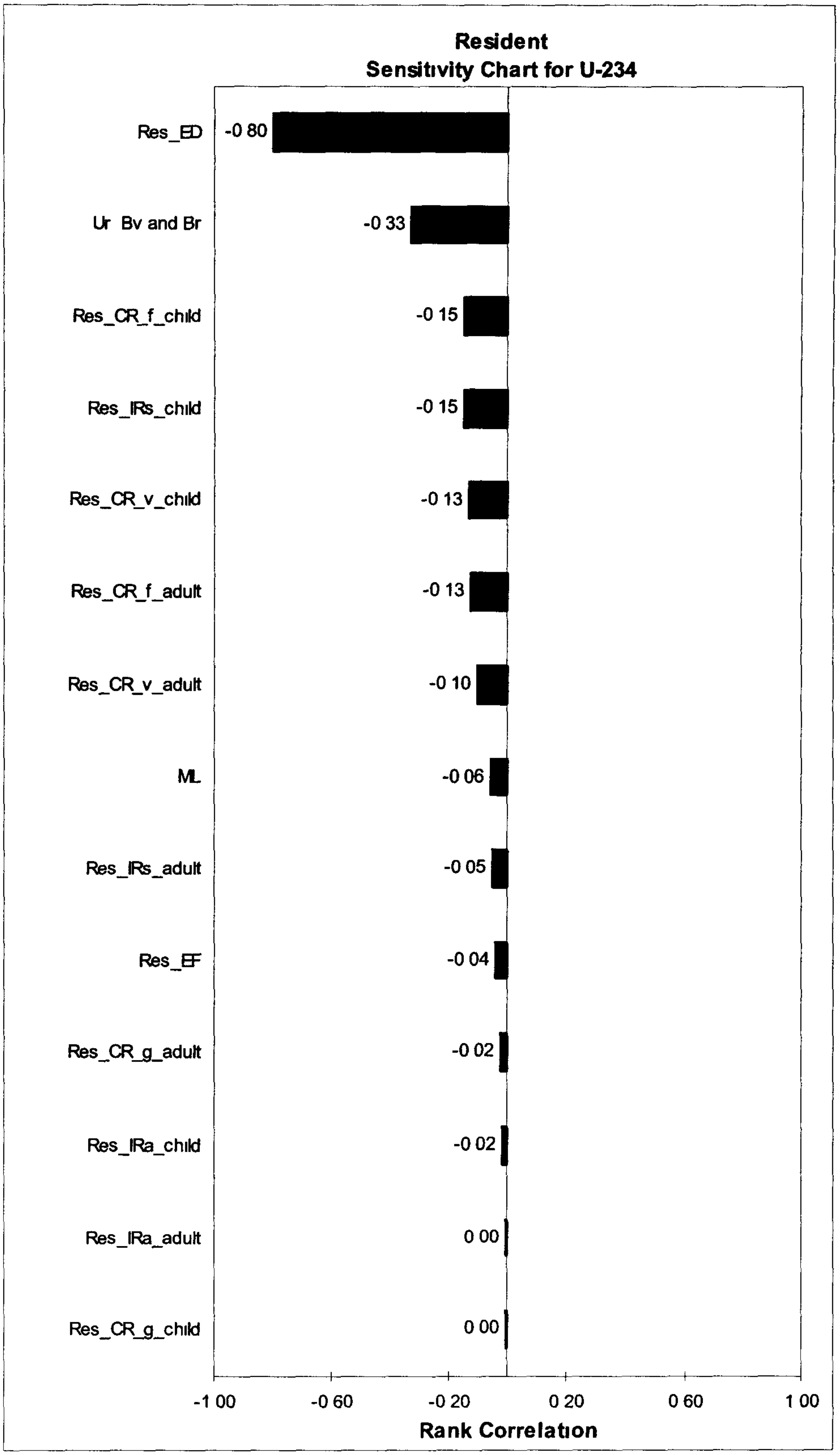

Figure H-7 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-234, rank correlation

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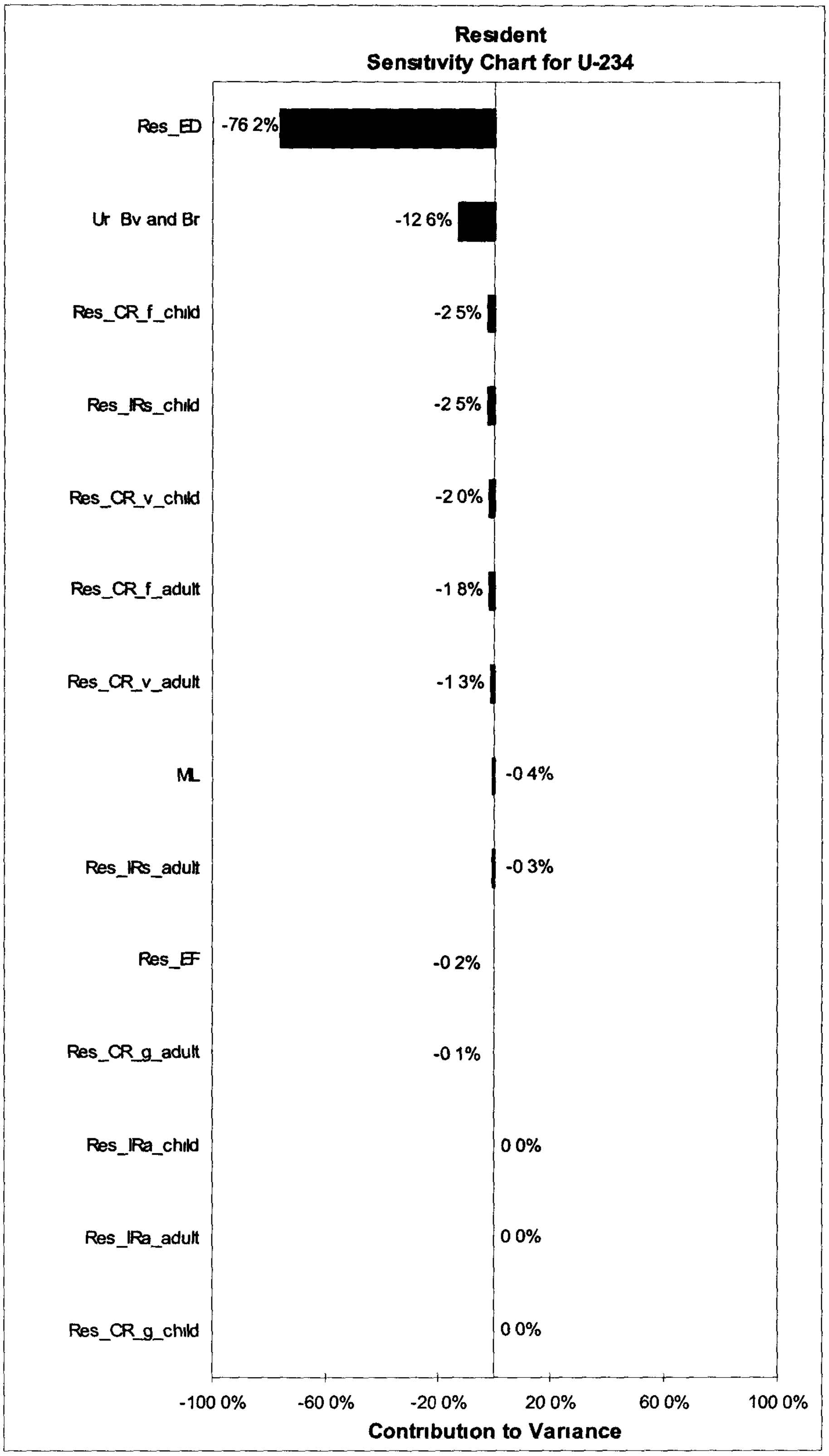

Figure H-8 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-234, contribution to variance

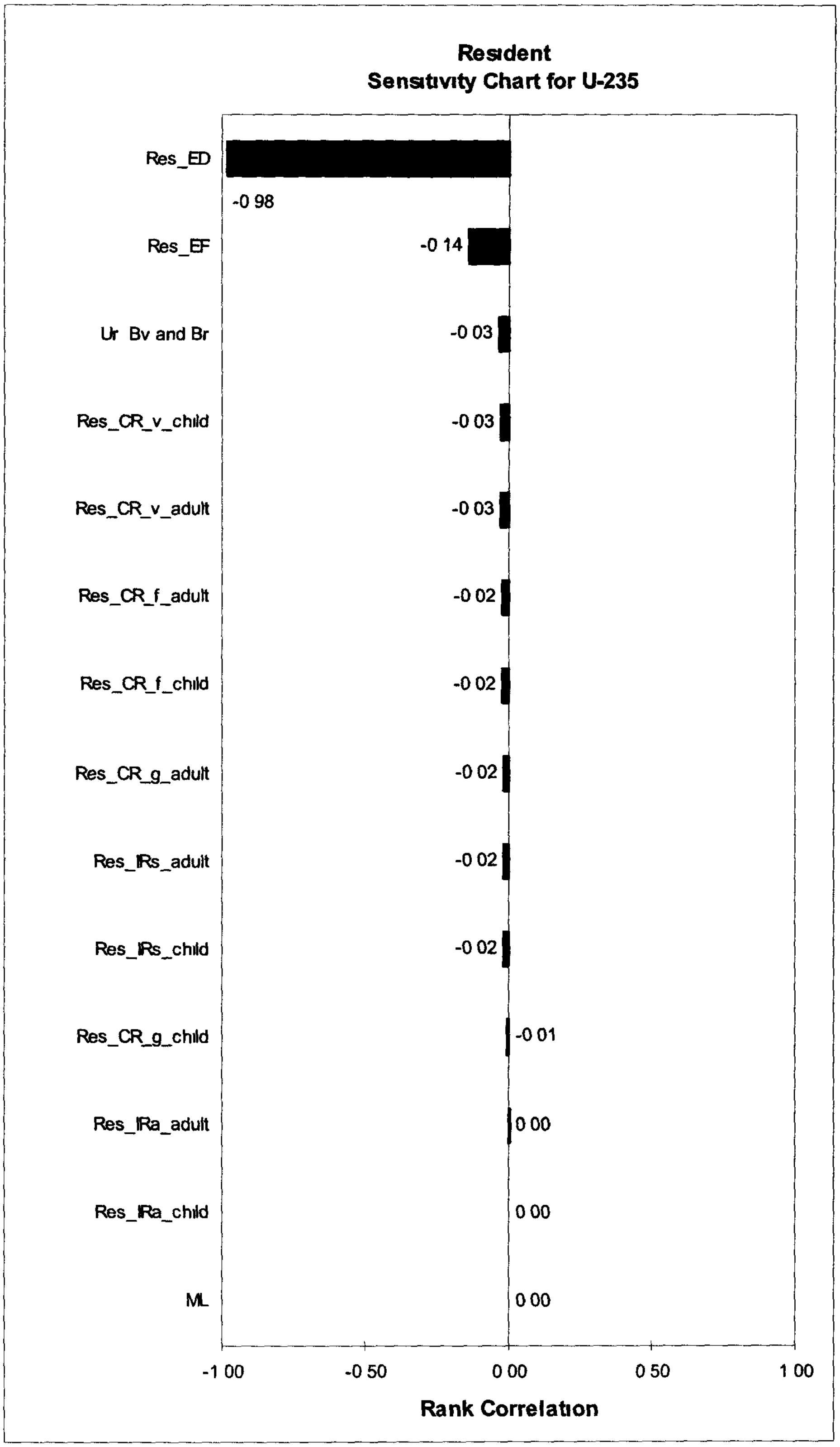

Figure H-9 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-235, rank correlation

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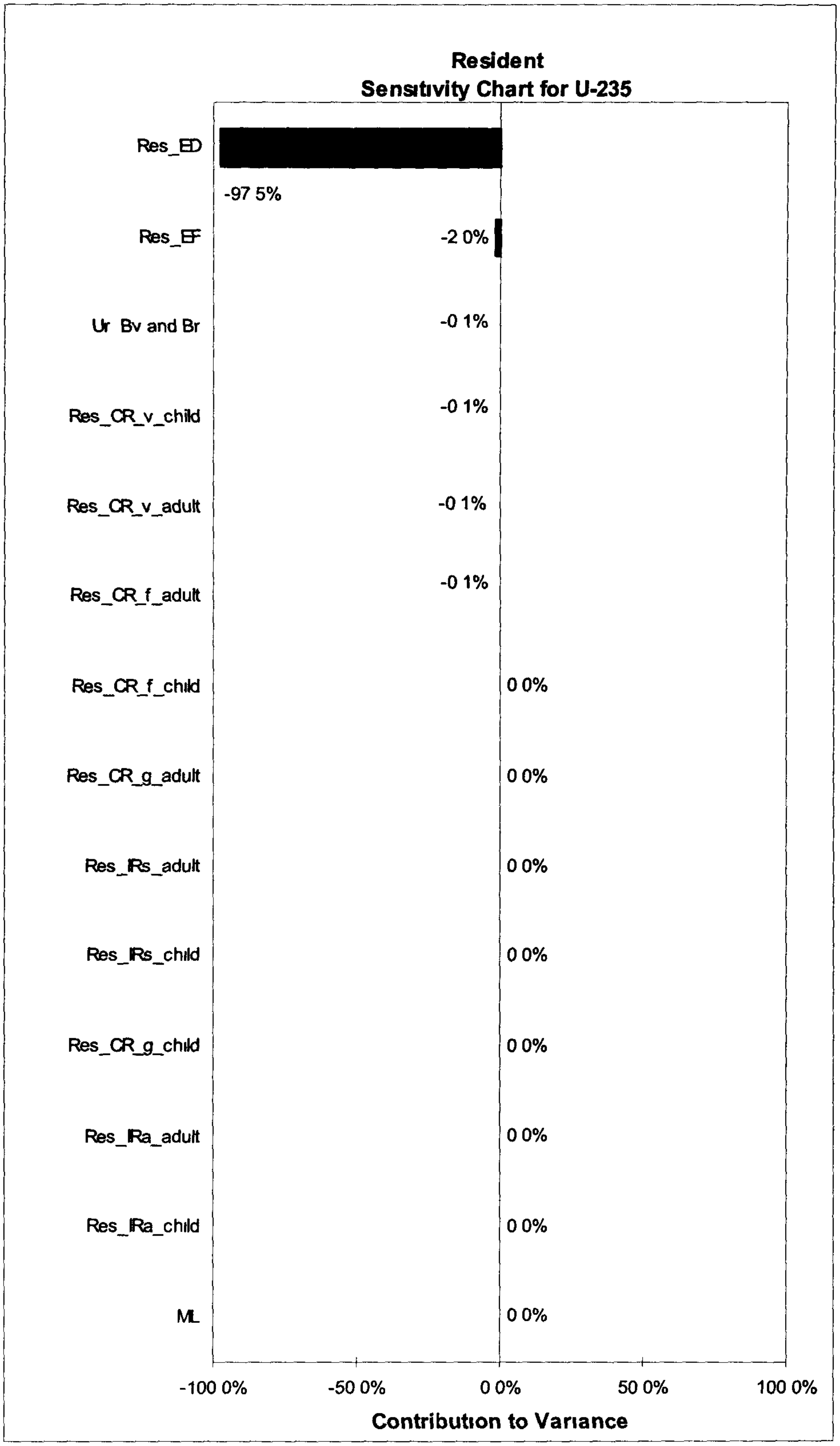


Figure H-10 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-235, contribution to variance

322

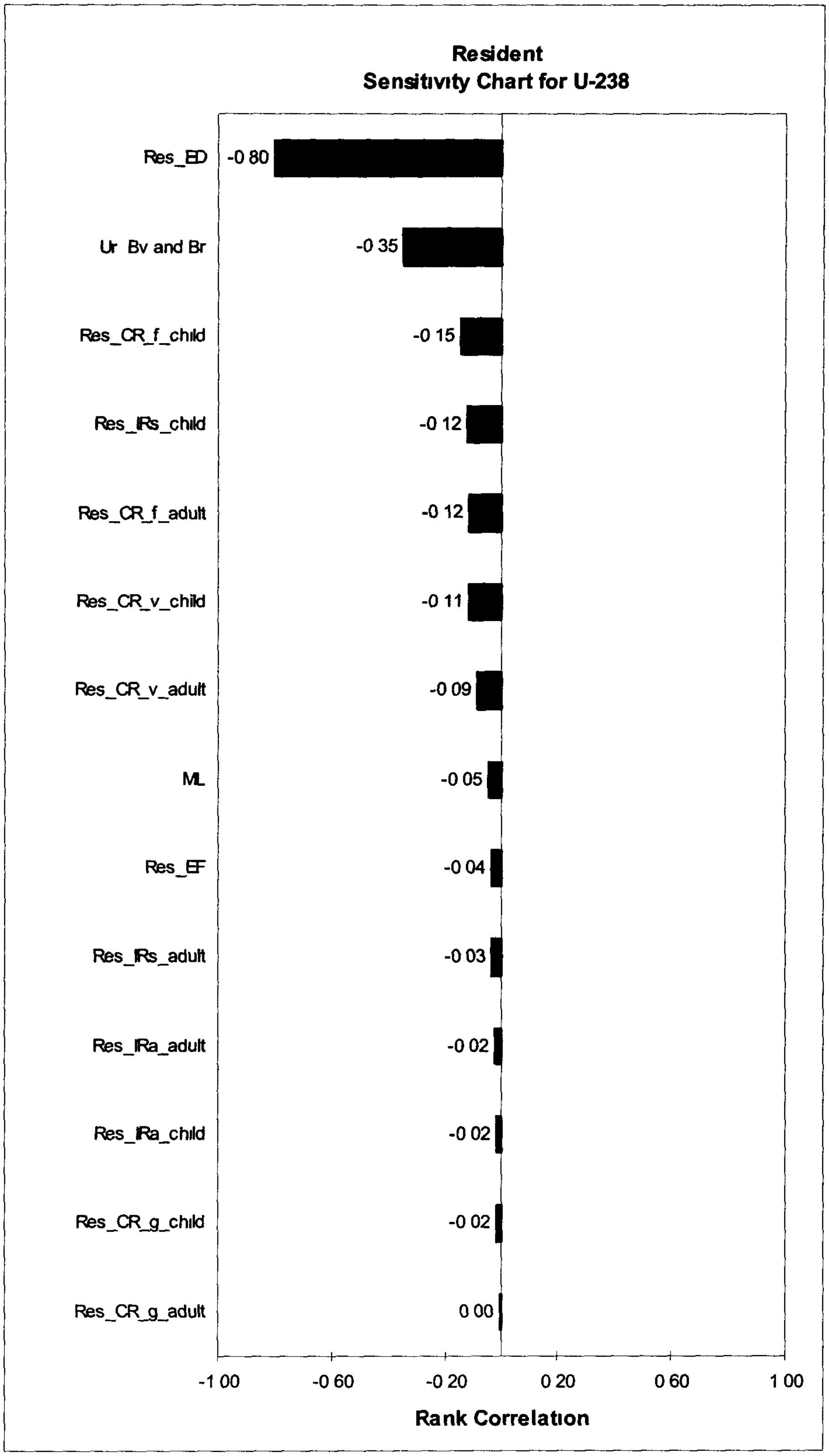


Figure H-11 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-238, rank correlation

322

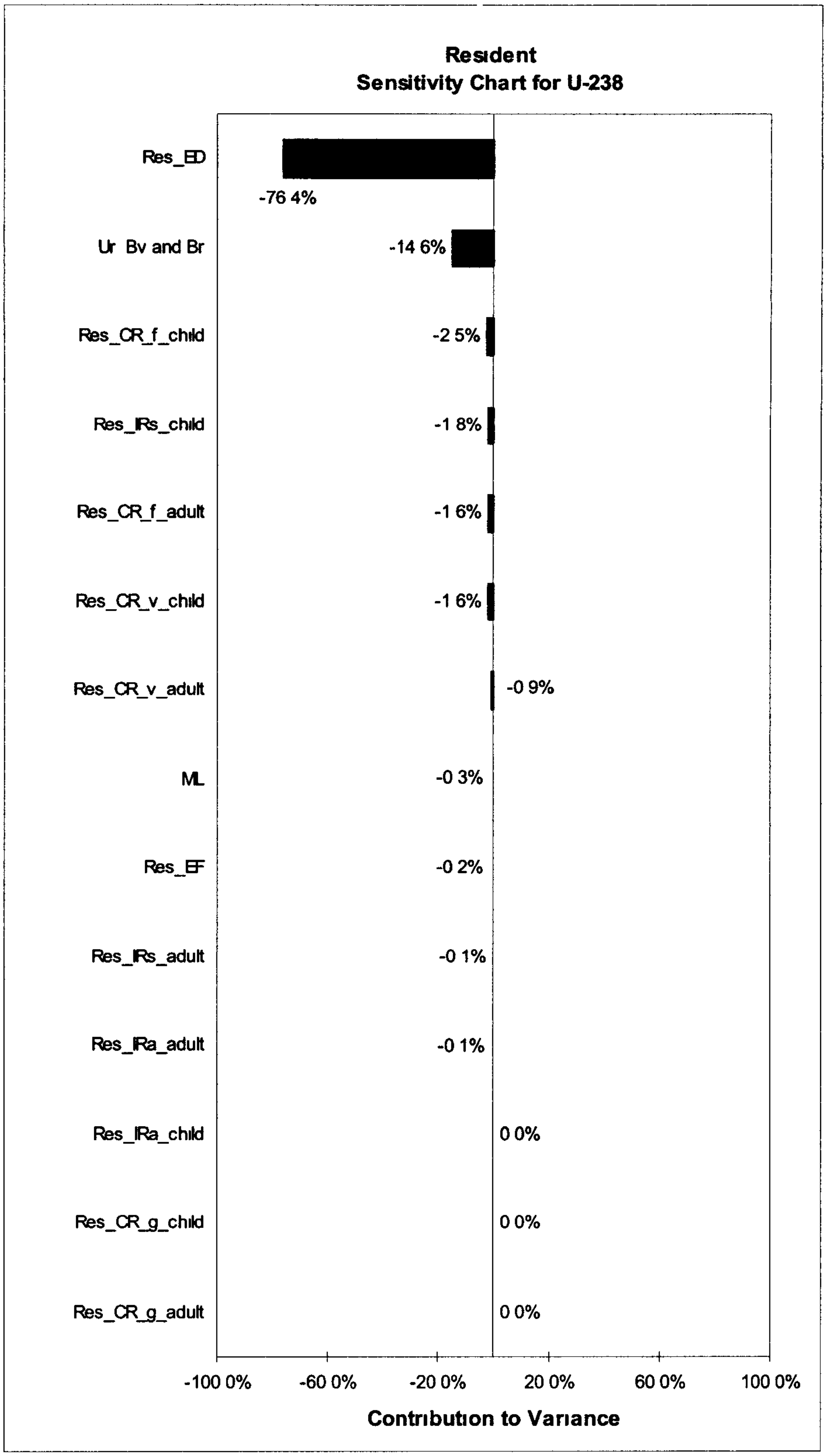


Figure H-12 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-238, contribution to variance

323

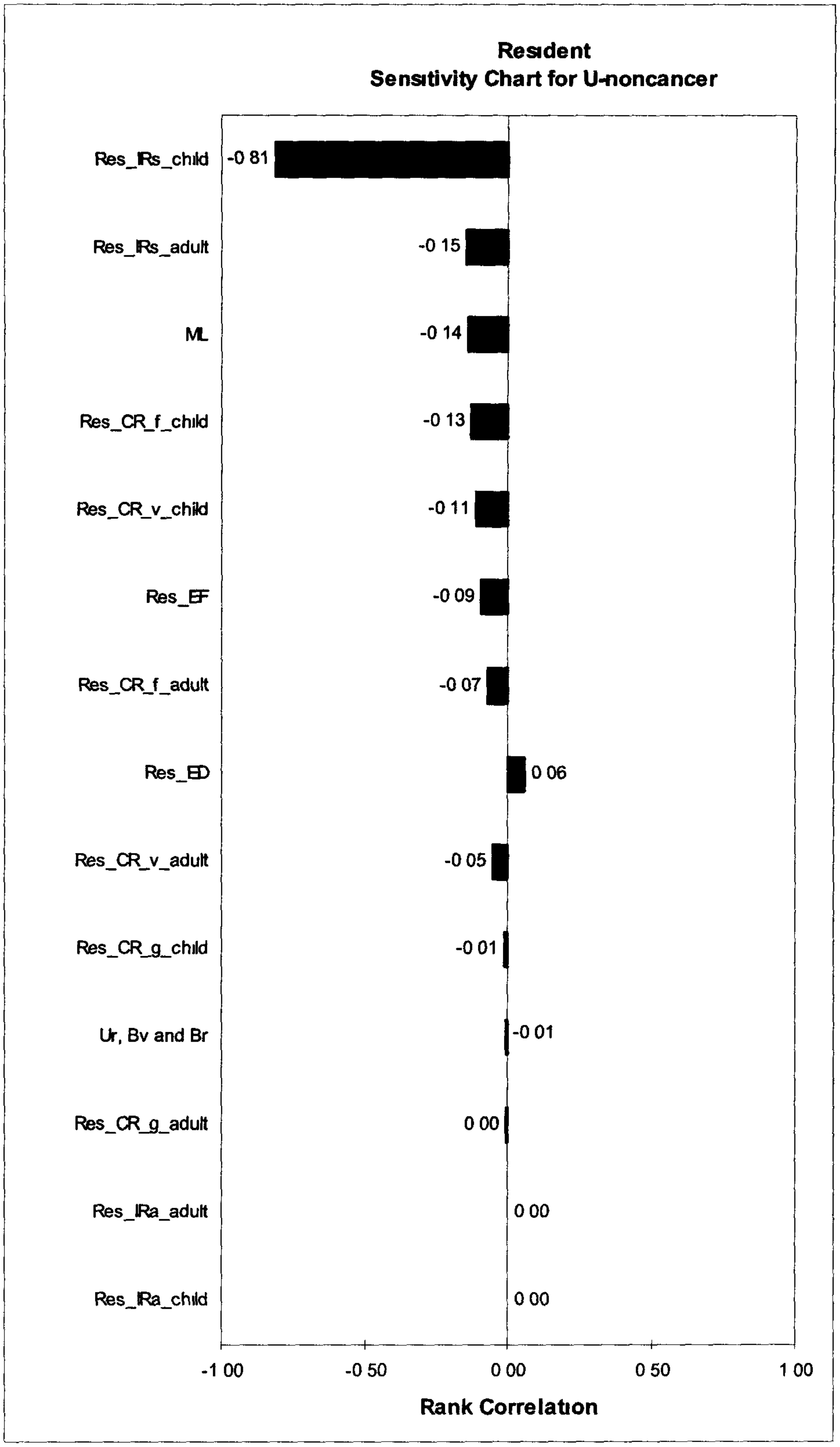


Figure H-13 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-non-cancer, rank correlation

324

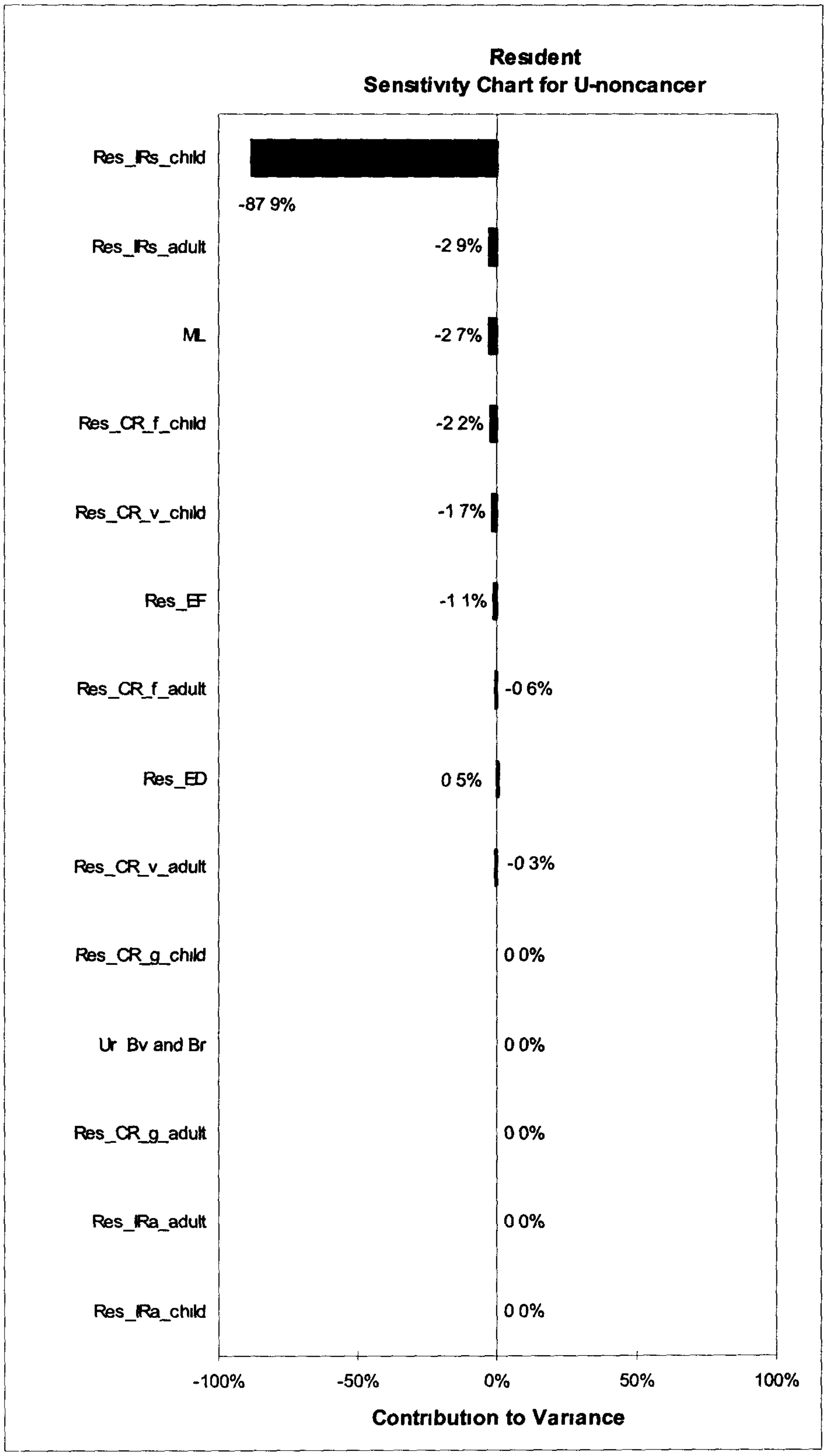
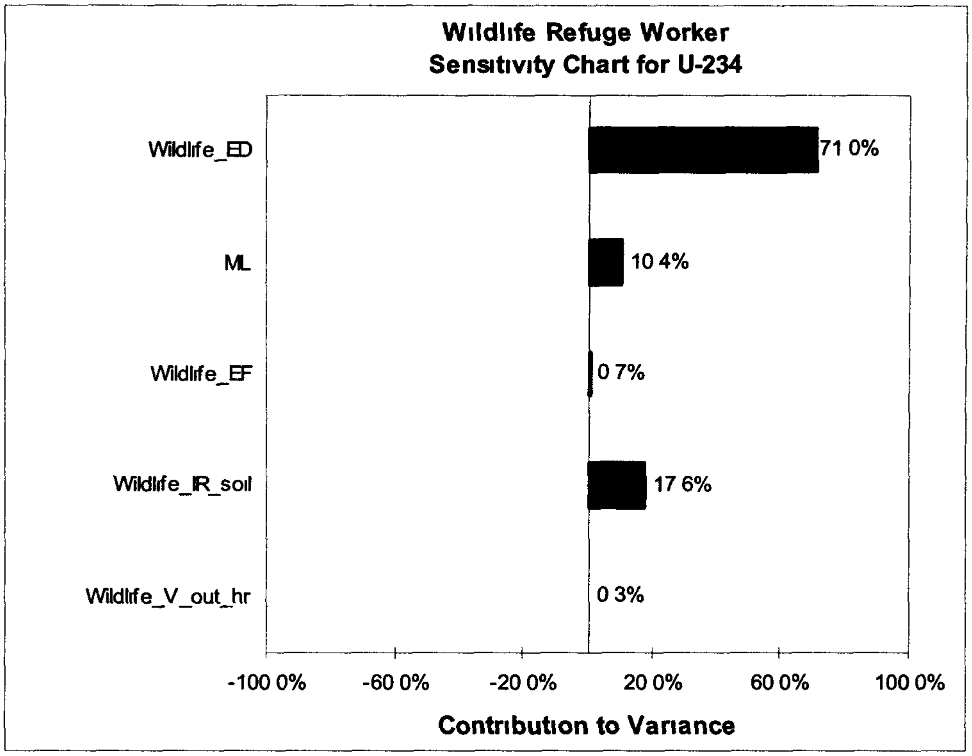


Figure H-14 Probabilistic sensitivity analysis results for Standard Risk equations – rural resident, U-non-cancer, contribution to variance

325



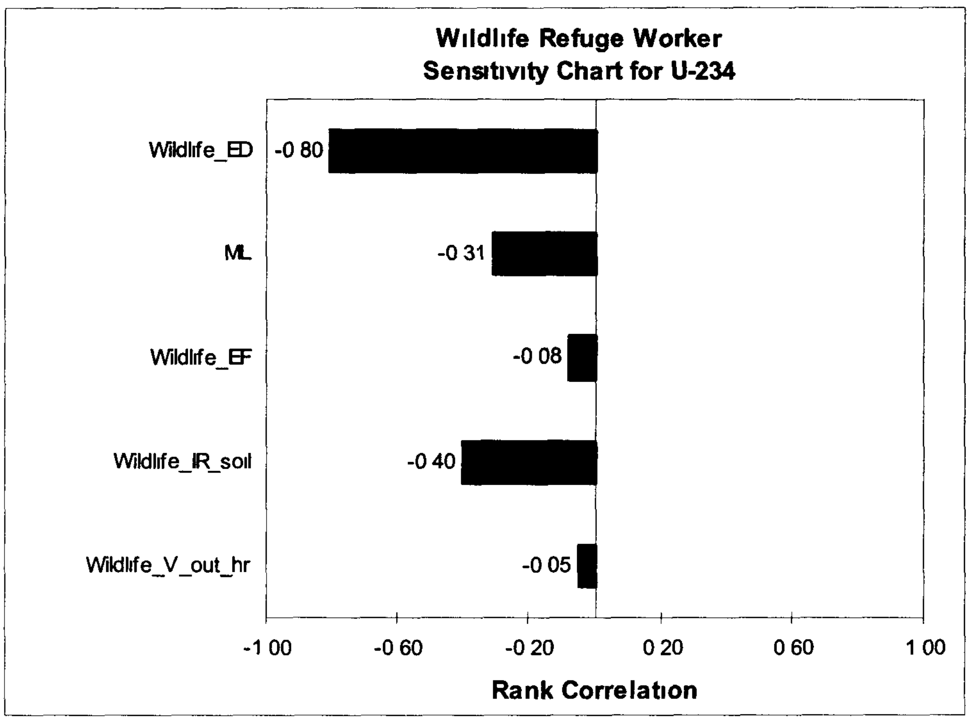


Figure H-15 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, U-234, contribution to variance (top) and rank correlation (bottom)

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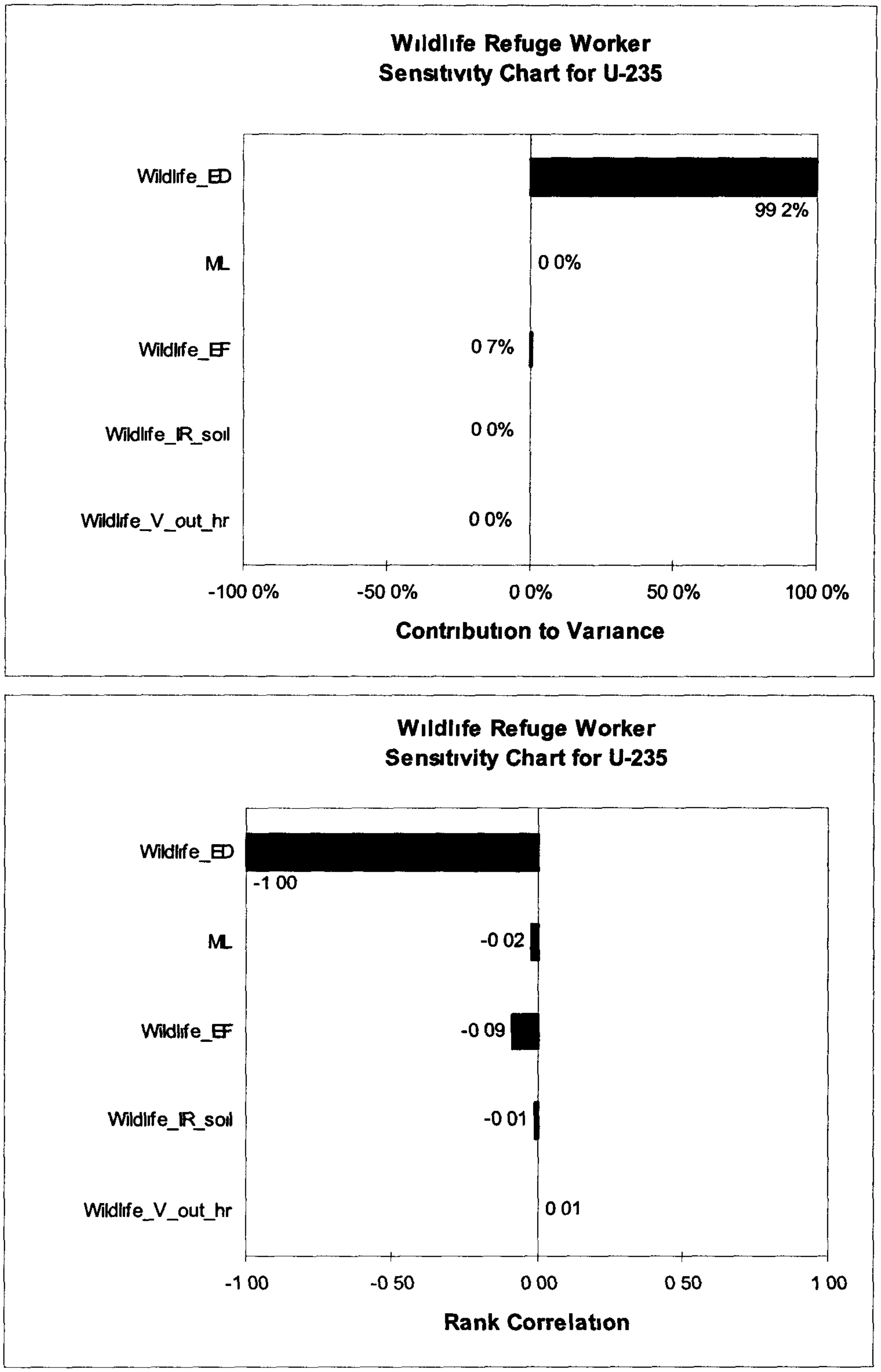
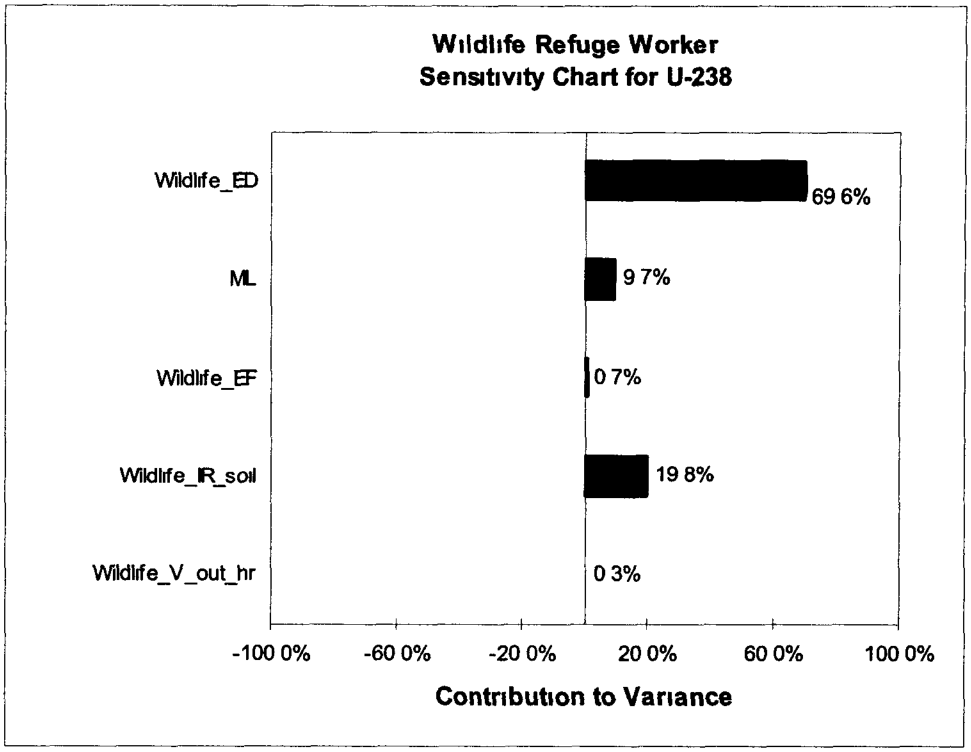


Figure H-16 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, U-235, contribution to variance (top) and rank correlation (bottom)

327



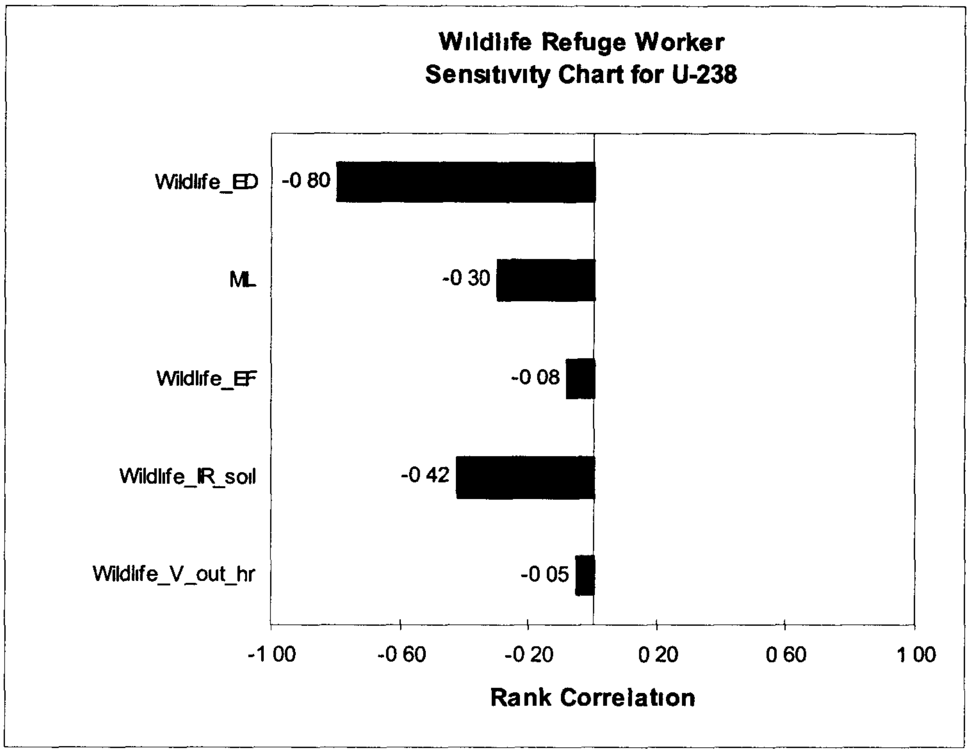
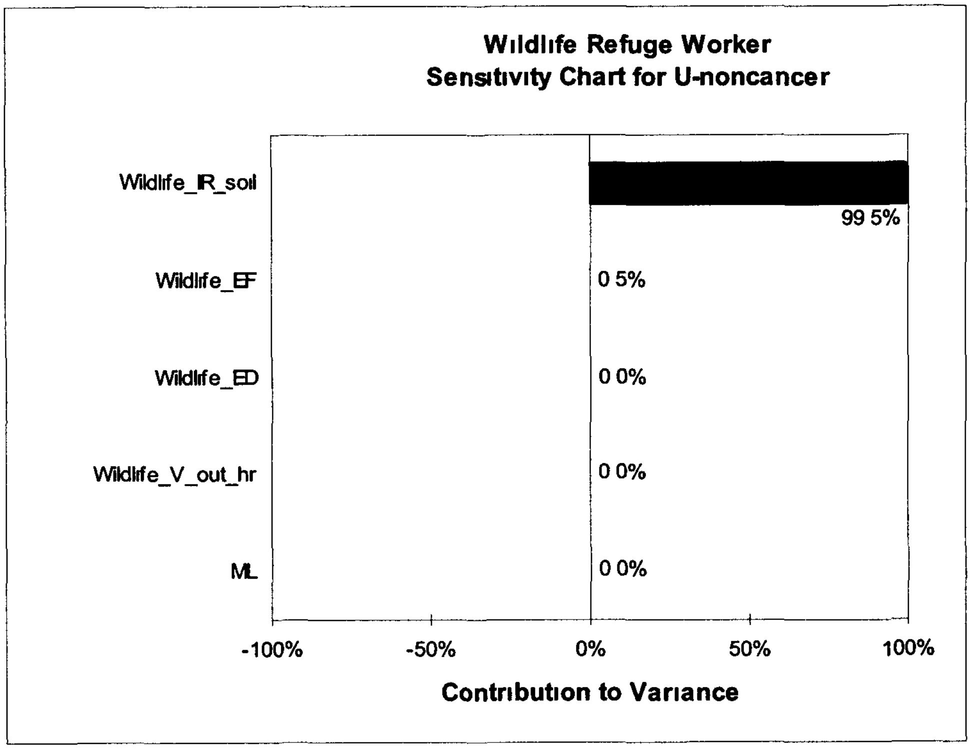


Figure H-17 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, U-238, contribution to variance (top) and rank correlation (bottom)



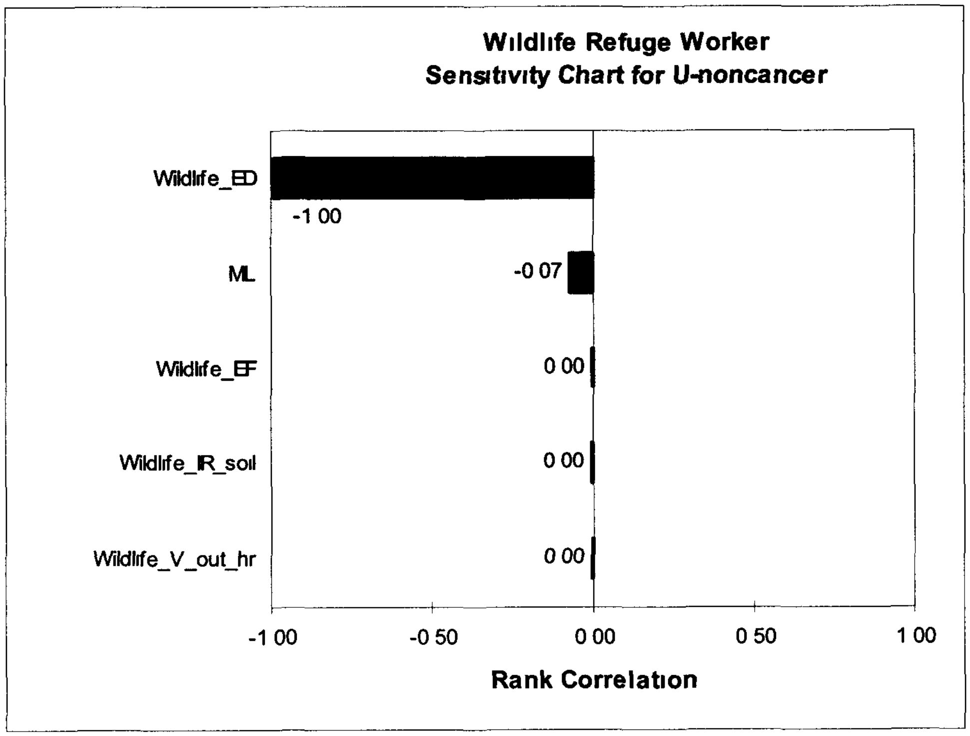


Figure H-18 Probabilistic sensitivity analysis results for Standard Risk equations – wildlife refuge worker, U non-cancer, contribution to variance (top) and rank correlation (bottom)

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APPENDIX I
RESPONSE TO COMMENTS

	Review Comments – Wind Tunnel Reviewer #1	Response
	General Comments	
1	A key question is how much saltation-size soil and burn debris of similar size were mobile and would move downwind and generate additional PM-10 by breakage of the moving material and abrasion of the downwind surface at high wind speeds? The tunnel test results do not report threshold velocities for neither coarse particles nor measurements of the amount of these particles and burn debris removed during testing The implicit assumption in the wind tunnel test protocol was that incoming saltating soil and debris particles would be absent, and only wind would affect the test surface during a windstorm	The wind tunnel tests captured both coarse particles and burn debris eroded from each test plot as wind speeds increased over the course of each test This material was segregated into ≤10 micrometer (μm) and >10 μm particle sizes, aerodynamic equivalent diameter It is reasonable to assume that larger particles (>PM_{10}) captured in the cyclone may include saltating particles that entered the wind tunnel inlet However, since the concentration of particulate matter entering the wind tunnel inlet was subtracted from the wind tunnel effluent concentration, only the net impact of such particles on the wind tunnel test plot are included in the measured erosion potential of each wind tunnel test That is, only the particles eroded from the test plot through saltation by incoming particulate or wind shear are counted in the test plot erosion potential Assigning threshold velocities to individual surface sites has limited applicability to natural soil surfaces given the complexity and heterogeneity of such surfaces While the threshold velocity for a given particle size may be determined with some reliability for a storage pile or similar homogenous surface, surfaces as complex as the Rocky Flats buffer zone do not lend themselves to such characterization within reasonable bounds of confidence
2	The test wind tunnels are probably too small in cross-section and too short in length to accurately simulate atmospheric boundary layer flow over a significant portion of the test section on the rough, test surfaces at Rocky Flats Second, some of the roughness elements were large, relative to the tunnel size, thus creating blockage effects There are also edge effects where the tunnel sides meet the uneven ground surface	While the portable wind tunnel does not generate the larger scales of turbulent, motion found in the atmosphere, the turbulent boundary layer formed within the tunnel simulates the smaller scales of atmospheric turbulence It is the smaller scale turbulence that projects wind flow into direct contact with the erodible surface and contributes to particle entrainment (macro-scale turbulence must still penetrate ground cover and liberate erodible material on a micro-scale) As was observed by Peer Reviewer 2, the ratio of the test section length to the roughness length is greater than 100 1, providing a good indication of boundary layer development The main reason for assuring boundary layer development and stability is to characterize and control the shearing stress on the surface

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	Review Comments – Wind Tunnel Reviewer #1	Response
		The confounding effects of surface roughness elements and uneven test plots are mitigated in the test protocol For example, standing vegetation was trimmed prior to testing to prevent the deformation of vegetation by the working section, which leaves the potentially-erodible particle reservoir at the base of the vegetation undisturbed but minimizes the damping effect of the standing vegetation on centerline wind speed Edge effects were mitigated through selection of relatively level test plots and the use of weighted skirts along the sides of the working section, which protected against air and particle infiltration
3	Another difference between the wind tunnel and atmospheric winds is that the latter vary in the wind direction about the mean direction The directional fluctuations during a storm would likely increase total PM-10 discharge a few percent above that measured from the straight winds in the wind tunnel	It is true that small amounts of erodible material may be sheltered by surface roughness elements from the entraining energy of the wind tunnel due to a predominant wind direction However, the boundary layer generated at soil level is not uni-directional, having turbulent eddies and wakes created through wind interaction with surface elements This turbulence reduces the sheltering effect of surface irregularities, as observed by the experimenters
4	Because the soil [at Rocky Flats – ed] is a 'limited source' some period of time may be needed between wind events to replenish the loose particles through weathering, deposition, or disturbance processes The 'limited source' concept means that when considering potential emissions on successive days following a windstorm, the present tunnel results would tend to overestimate the PM-10 available for resuspension	The wind tunnel test results clearly illustrate the 'limited reservoir' nature of erodible surface material following each step in wind speed Real-time optical particle counter data show rapid decays in particulate concentration over time following each step-increase in wind speed Over-estimation of PM_{10} erosion potential is acceptable to the working group given the end use of the data to develop final Radioactive Soil Action Levels (RSALs)
	Specific Comments	
5	The selection process for the test plots was not described, but there is considerable scatter among plots in the potential erosion data	The prescribed burn wind tunnel test location was selected within a region of homogenous soil type, similar standing vegetation, and relatively flat topology within the test burn acreage Prior to the prescribed fire, the test area was staked off and protected from anthropogenic impacts other than the fire itself Individual test plots for each temporal iteration were adjacent, to maximize similarity of the test surfaces (i e , the April burned-surface test plots were adjacent to one another, the May test plots were nearby the April plots and also adjacent to one another, etc) Individual test plots were sampled in sequence, with no repeat testing of any surface and no anthropogenic disturbance of any plot prior to testing No effort was made to limit natural disturbances prior to testing (rain splash, wildlife intrusion, etc)

	Review Comments – Wind Tunnel Reviewer #1	Response
		Scatter of results in wind tunnel testing is typical, and is well documented in portable wind tunnel test literature including the background documentation for EPA-recommended industrial wind erosion emission factors presented in Compilation of Air Pollutant Emission Factors (AP-42) The scatter typically results from the complexity and heterogeneity of surfaces tested, even relatively homogenous surfaces such as storage piles demonstrate detectable differences in the erodibility of individual areas The forces that inhibit erosion (surface moisture, static attraction, crusting, surface roughness elements, etc) are not uniform regardless of macro-scale homogeneity among test surfaces Additionally, the air stream turbulence that causes particle entrainment has a significant degree of randomness To ensure satisfactory statistics between replicate results, three wind tunnel trials were combined into each test run, and three test runs were bounded and averaged to describe each test condition As noted by Peer Reviewer 2, " in order to characterize differences in surface cover and surface roughness, the tunnel has to be moved several times and the tests replicated That gives satisfactory statistics between replicate results " This was accomplished
6	It is also not clear how well the selected tunnel test plots might represent the contaminated areas that will be subjected to fires Additional measurements to characterize the soil and vegetation conditions at the test sites would have been useful for interpreting the wide variability in the test results and estimating applicability of the test site data to comparable contaminated areas	While the performance of pre- and post-fire erosion potential measurements on plutonium-contaminated regions of concern would provide the best site-specific data in support of RSAL development, pursuit of such experiments is unlikely to gain approval Fortunately, the geologic units underlying both the prescribed fire plot and the tablelands east of 903 Pad are identical (Rocky Flats Alluvium), and support these data as being representative of contaminated areas Soils underlying the prescribed fire were top-slope cobbly sandy loams, while the contaminated area soils consist primarily of top slope cobbly sandy loams and side slope clay loams Vegetation varies between xeric tallgrass (burn area and contaminated tableland) to mesic mixed grasses (contaminated hillside) and reclaimed mixed grasses (previously remediated areas) Though these differences may contribute to minor variance in erosion potential, the bounding of wind tunnel study data and the conservative analysis of that data mitigates these subtle differences [SOURCE *Report on Soil Erosion and Surface*

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	Review Comments – Wind Tunnel Reviewer #1	Response
		Water Sediment Transport Modeling for the Actinide Migration Evaluation, 00-RF-01823 (2000)]
7	Unfortunately, neither the measurement heights nor the measured values for the wind speed profiles were reported in the data However, the practical result of the scaling problems cited above mean that the aerodynamic roughness and friction velocity values obtained from the wind speed profiles in the tunnel should be regarded only as rough estimates As a consequence, the atmospheric wind speeds at the 10 m height calculated from these values also should be considered only as rough estimates	Wind tunnel centerline wind speed was measured at 11 points between 0 5 and 15 2 centimeters (cm) above soil surface The specific heights were 0 5, 0 7, 1 0, 1 4, 2 0, 2 8, 3 8, 5 0, 7 0, 10 0, and 15 2 cm, respectively, selected to fit a logarithmic distribution The average roughness length of all test runs for a given temporal scenario (i e , all nine wind tunnel trials that comprised three test runs for each scenario) was used to estimate 10-m equivalent wind speed, as detailed in the example calculation in Appendix D of the controlled-fire test report The small variations in roughness length observed between trials, while real, have negligible impact on the estimated 10-m equivalent wind speed given that wind speed varies as the natural log of the corresponding roughness length More to the point, the importance of precision and accuracy when estimating the equivalent 10-m wind speed for each wind speed step is minimized by the use of normalized 95 mph wind speeds to describe erosion potential from soil surfaces The conservatism that is built into the post-fire mass loading multipliers by normalizing wind speeds to 95 mph more than compensates for any uncertainty extending from the well-documented relationship between surface roughness length and equivalent wind speed at a given height above ground
8	To increase accuracy of tunnel estimates it would have been useful to have a cyclone preseparator on the ambient PM-10 filter	Because the <u>wildfire</u> report examined the very low concentration of actinide in airborne dust particles and compared it to the actinide concentration in the underlying soil, it was critical to the precision and accuracy of the ambient background correction that the PM_{10} to TSP ratio be known Therefore, Colorado Department of Public Health and Environment data from ambient air particulate matter samplers located within several hundred yards of the wildfire area were queried and the average PM_{10} TSP ratio for the area determined to be 0 3895 For the <u>controlled</u> burn data correction, where the results were used to develop post-fire erosion potential multipliers based on comparisons of erosion from adjacent burned and unburned plots, an estimate of the background correction was sufficient As the following sensitivity analysis shows, the error introduced by assuming a PM_{10} TSP ratio of 50% was small

	Review Comments – Wind Tunnel Reviewer #1	Response
		Test Run CB-7 (from Appendix D) Wind-tunnel PM_{10} net mass 9 15 mg Background net mass 8 49 mg Estimated (50%) PM_{10} background mass 4 24 mg Calculated (38 95%) PM_{10} background mass 3 31 mg PM_{10} erosion potential (50% ratio) 0 12 g/m2 PM_{10} erosion potential (38 95% ratio) 0 14 g/m2 The calculated (38 95%) background PM_{10} correction would result in a net growth in erosion potential for both burned and unburned plots Remember, however, that the end use of the data is to develop a post-fire mass-loading multiplier by calculating the ratio of burned to unburned plot results That multiplier contains the same PM_{10} correction in both the numerator and the denominator Since the denominator is a smaller erosion potential (unburned) than the numerator (burned), a decrease in the PM_{10} correction, as reflected here, would result in a smaller post-fire multiplier By using the estimated background PM_{10} correction, the multiplier used in the RSAL calculations is larger than it should be, hence is conservative
9	The post-fire erosion potential multiplier for the spring fire appears to be a reasonable application of the measured wind tunnel results This is partly true, because precipitation events near the burn event are more frequent than at other seasons	Seasonal differences in vegetative recovery, with the resultant effects on surface erosion potential, were considered during analysis of the wind tunnel data The resulting post-fire erosion multipliers are qualified for seasonality See comment 10 for additional discussion
10	The post-fire erosion potential multiplier for the fall fire is estimated without a clear basis	According to local ecologists, vegetative recovery will occur along a similar trajectory regardless of the time of year a fire occurs – the start of significant recovery is simply delayed in a late-season fire until the following spring growth cycle Some "green up" would occur immediately after a fall fire, but plants would send up only a few inches of new growth out of plant crowns It is likely that only the grass species would send up much growth, forbs would not be likely to respond substantially until spring This contrasts with a spring fire where both grasses and forbs would begin growth immediately and continue to full plant height, thus reducing wind speeds at the ground surface and the potential for wind erosion more quickly Since the vegetative recovery trajectories are similar,

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	Review Comments – Wind Tunnel Reviewer #1	Response
		the shapes of the erosion multiplier curves (a function of vegetative recovery) would also be similar, though the initial fall fire multiplier (y-intercept) is greater because a fall fire has more and dryer fuel available than a spring fire and generally taller and denser standing vegetation The fall y-intercept value was determined experimentally as the ratio of burned-area to unburned-area erosion potential measured in June (which was much higher than the same ratio measured in April due to greater unburned vegetation density) Fitting the spring fire multiplier curve to the fall y-intercept value produced the estimated fall fire multiplier curve, which is integrated to annualize the multiplier
11	The estimated multipliers shows fall fire raises the erosion potential for 24 months It is not clear that the second 12 months was counted in the frequency distribution matrix Table IV-5 page 45 The second year of exposure following a fall fire would likely result in less mass loading than the spring fire scenario, but more than the median non-fire scenario Such events were included in the mass loading distribution as more probable than would normally be observed, because of the manner in which the empirical mass loading distribution was developed	Both RESRAD and the risk assessment guidance consider a series of annual exposures in developing the probabilistic RSAL The probabilistic risk assessment used the "fall" fire events in this same context While it is true that multiple-year events would be correlated for a fall fire, one must also recognize the overall uncertainty that is implicit in the mass loading distribution developed for a fall fire The fall fire scenario is predicated on the false assumption that every six-month period has the same post-fire recovery characteristics The development of the mass loading distribution also assumes fall fires have the same probability as spring fires, despite the fact that spring fires are known to occur over the six months of the year with the greatest recovery potential <u>and</u> the greatest likelihood for natural wildfires Remember that the contaminated areas are well isolated from other fire influences such as cigarettes, sparks from vehicles, etc , yet a wildfire is postulated to occur once every ten years on the 300 contaminated acres of a 6400 acre site The wildfire is thus assumed to occur with a frequency much greater than would be expected due to natural occurrence Together, these factors cause the fall fire to have a much higher estimated frequency than would actually be expected This suggests that its weighting in the distribution is greater than warranted, and is likely to offset any reduced effect resulting from neglect of multiple-year correlation In addition, for the long-term risk exposure calculations, the working group did not exclude multiple consecutive-year fires on the contaminated

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	Review Comments – Wind Tunnel Reviewer #1	Response
		area While fires could occur two years in a row on the same area, the second fire would in reality be of significantly reduced intensity compared to the first, and compared to the one whose effects were studied using the wind tunnel By not excluding such events, a more conservative risk assessment than is realistic results
12	While the estimates for annual erosion multipliers appear reasonable for use in RESRAD and RAGS, the submitted material is difficult to evaluate because of the absence of information about topography, soil texture, surface roughness, rock cover, etc High winds have a great capacity to move erodible soil, so the statue of the surface when high winds occur is the major control factor To illustrate the effect of high wind speeds after a fire on a sandy soil that is not a 'limited source', see the attached photo taken in southwest Kansas in 1996 If there are contaminated areas that could act as unlimited source areas during high wind speeds, the rarity of these events would not greatly impact the annual values of PM-10 used in RESRAD Nevertheless, such wind events could act to greatly expand the area of contaminated surfaces at Rocky Flats Hence, it would seem important to identify, stabilize, and restrict activity on those portions of the contaminated areas that might become highly erodible, if the vegetation were removed Such measures would help to insure that the assumptions such a 'limited sources' made in developing the RSAL remain valid	RESRAD and RAGS outputs are independent of intermittent changes to soil surface condition provided the mass loading inputs to these models adequately account for such changes on an annualized basis Given the current, well-vegetated condition of the Site's areas of contamination, the characteristic crusting that occurs in cobbly and clay loams that are characteristic of the contamination areas, and the land-use scenarios under evaluation, an infinite-reservoir model would not be "reasonable" unless major, repeated disturbance of the soil surface were assumed (e g , intensive large-scale agriculture) which was rejected as a reasonable post-closure land use If studied, any such disturbance that would increase potential short-term dose to downwind receptors would also dilute surface contamination through mixing with uncontaminated subsurface soil Therefore, any hypothetical evaluation of long-term dose effects from a disturbed, unlimited reservoir source term must consider the reduced specific activity of the radioparticulate source compared to the existing limited-reservoir surface contamination

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	Review Comments – Wind Tunnel Reviewer #2	Response
	General Comments	
1	The appropriateness of this wind tunnel application should be thought of in the proper context The wind tunnel is artificial in many ways It is designed in a way that controls the mean wind speed but cannot reproduce the scale (size) of wind speed variations ("turbulence") The ground area exposed to controlled wind erosion is only about one square meter but the variability should be significant between adjacent square meters due to differences in surface condition So testing several one-square-meter plots becomes essential Using this method the equivalent 10-m wind speeds reported are very extreme Yet, the erosion potentials so obtained have use in establishing Radioactive Soil Action Levels, providing that we expect that the extreme erosion potentials observed are unlikely to ever exist in nature	The reviewer's list of the limitations of an artificial evaluation of wind erosion from natural surfaces is well reasoned and comprehensive These limitations were mitigated through equipment design, protocol development, and strict quality control Specific concerns of the reviewer were addressed as follows While the portable wind tunnel does not generate the larger scales of turbulent motion found in the atmosphere, the turbulent boundary layer formed within the tunnel simulates the smaller scales of atmospheric turbulence It is the smaller scale turbulence that projects wind flow into direct contact with the erodible surface and contributes to particle entrainment As observed by Peer Reviewer 2, the ratio of the test section length to the roughness length is greater than 100 1, which is a good indicator of boundary layer development Sampling nine plots per test scenario (three plots per test run, three runs per scenario) provided sufficient replicates to describe differences in surface roughness This provided satisfactory statistics between replicate results It was desired that any bias present in the analytical method tend toward conservatism of dose estimation, therefore, the creation of sustained 10-meter equivalent wind speeds in the wind tunnel that were greater than could be reasonably expected based on historic meteorology is acceptable
2	It is a matter of controversy that erosion only occurs after a certain wind speed threshold More recent observations show that there is an emission of small particles at speeds below the observed thresholds for saltation, and while this amounts to a relatively small emission loss, it affects the surface condition	Evidence of the sub-threshold emission was seen in these studies By using mass loading rather than erosion potential to drive radionuclide transport and dose assessment, the role of wind speed threshold as a factor in radionuclide migration is minimized By assuming that all eroded dust is contaminated in a 1 1 ratio comparing airborne specific activity to soil specific activity, the mass loading approach accounts for sub-threshold wind erosion (Haines, et al , show the actual ratio for undisturbed burned soil to be less than 1 1 in *Correlating Plutonium Activity in Fugitive Dust to Plutonium Concentration in Surface Soils at Rocky Flats, Colorado,* (2001))
3	In the protocol, each test involves step increases in wind speed and adds accumulated emissions from each step In the wind tunnel saltation, the onset of avalanching may be a product of the peculiar small scale of	The wind tunnel is unable to exactly replicate the atmospheric conditions that may occur at the Site However, the methods applied appear to overestimate actual erosion potential Any conservatism created though the use of the approach is acceptable, given the

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	Review Comments – Wind Tunnel Reviewer #2	Response
	turbulence, and more soil might be available than under natural winds	application of these data toward RSAL development
	<u>Specific Comments</u>	
4	In answer to Focus Group Question 1, regarding equipment suitability for this application This reviewer feels that the equipment is in good standing with the scientific community	The working group concurs with this reviewer The fact that this equipment has been used extensively to develop emission factors for modeling industrial wind erosion in a regulatory setting (presented in US EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*) was considered an endorsement of the technique for the given application
5	In answer to Focus Group Question 1, regarding review quality and thoroughness, appropriateness and adequacy This reviewer will make an attempt to show that the observations made by the wind tunnel method provide a set of data that are sufficient to proceed with the determination of Radioactive Soil Action Levels For example, I hope to show that particular observations are sufficient to bound the worst-case possible inhalation scenario, while I acknowledge that normalizing the emission potentials to 95 mph winds are a bit of an extreme In my view there is no need for further study if all we need is to determine Radioactive Soil Action Levels No study may be more definitive in that respect	The use of 95 mph wind speed (10-meter equivalent) to normalize wind tunnel data is believed to be appropriately bounding, given that Peak wind speeds of 95 mph or more, while rare, are not unprecedented at Rocky Flats, Lesser wind speeds would not have exhausted the available limited reservoir of erodible material and would have required interpolating the upper region of the erosion potential multiplier curves developed through these experiments, and Statistics between replicate results were satisfactory
6	In answer to Focus Group Question 2, pitot tube adequacy for this application The pitot tube is essential even though various electronic velocity probes would be more elaborate I doubt that we would have any significant change to the results by finer profile measurements	The pitot tube method has two primary qualities recommending it for this application It is an EPA reference test method for determining air velocity in ducts, and It is sufficiently rugged for the field application (i e , it will not be compromised by particle impacts or contact with the ground
7	In answer to Focus Group Question 3, regarding working section dimensions for developing desired wind conditions While details [of the wind tunnel design – ed] are not discussed in the reports, this is not a new tunnel design, and I believe that the design is adequate The ratio of the test section length to the roughness length is greater than 100 1, which is a good indicator of boundary layer development The main reason for assuring boundary layer development and stability is to characterize and control the shearing stress on the surface The wind tunnel does that adequately	The prescribed burn wind tunnel is one of two reference wind tunnels used by Midwest Research Institute (MRI) to develop the emission factors for industrial wind erosion presented in US EPA's *Compilation of Air Pollutant Emission Factors (AP-42)* [NOTE The reviewer's comment on the adequacy of the wind tunnel test section to develop stable boundary layer conditions speaks to a number of other comments]

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	Review Comments – Wind Tunnel Reviewer #2	Response
8	In answer to Focus Group Question 4, regarding small-scale effects of surface cover and roughness One limitation of this wind tunnel design is the small working area of the tunnel on exposed soil In order to characterize differences in surface cover and surface roughness, the tunnel has to be moved several times and the tests replicated That gives satisfactory statistics between replicate results	Adequate replicates were performed to ensure representativeness and satisfy quality criteria, as expressed in response to prior comments
9	Continuing the answer to Question 4, regarding small scale turbulence Turbulent variations on a small scale are abnormal in this wind tunnel, however, inlet flow conditioning serves to remove the natural large-scale turbulence and create small-scale turbulence The result is that flow variations are high-frequency causing particles on the surface to oscillate, something that would not be as important in nature The concept of soil binding is that the release of any particle does not occur until the aggregate containing the particle is stressed by force imbalance Oscillations cause different forces than direct shearing stress An abnormal surface particle behavior may explain why dust concentrations as measured by the tunnel effluent appear to this reviewer to be very large, and gives cause for concern that the tunnel method over estimates emission loss and erosion potential In my opinion, the larger values of PM-10, TSP, and erosion potential reported may be construed as upper bounds, and thus provide a factor of conservatism to protect against unusual inhalation exposure	Regardless of the mechanism of individual soil particle liberation from the soil matrix, the small-scale turbulence created in the wind tunnel boundary layer (in lieu of large-scale shearing forces) appears to fully deplete the material available for erosion Given the end use of the data, the potential excess in the resultant erosion potential is acceptable to the working group
10	In answer to Focus Group Question 5, regarding surface roughness acting to retard release of surface particles At the high speed in the wind tunnel it is likely that once a particle is in motion it remains in motion until it exits the test section	Scouring of the internal surfaces of the wind tunnel at peak wind speeds is well documented by MRI in these and prior experiments, consistent with the reviewer's comment Experimenters have observed that particle entrainment continues at least to the sampling point once a particle is liberated from the test surface
11	In answer to Focus Group Question 6, regarding appropriateness of sampling period The sampling period is "appropriate" for this particular protocol The soil material measured at the tunnel exhaust is the integration of all the observed peaks and the	The sampling period was appropriate because it allowed essentially all available particulate matter to be eroded at every wind speed step before increasing the speed to the next level Wind speed steps of approximately 2 m/s (5 mph), from zero to the maximum wind speed attainable for the given surface

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	Review Comments – Wind Tunnel Reviewer #2	Response
	data are summed over all previous wind speed step changes	condition, continued until the full wind speed potential of the tunnel was reached for each test plot (NOTE differences in the roughness length of individual test plots resulted in different observed peak wind speeds between test runs) Each step in wind speed proceeded only after optical particle counter data showed a return to baseline particle count rates See Figure 3 of the controlled burn report
12	In answer to Focus Group Question 7, regarding ability of wind tunnel to reproduce actual meteorological conditions expected during high winds at Rocky Flats, and the availability of validation data The wind tunnel causes resuspension only by increased shearing stress on the surface (measured by friction velocity) Wind records at Rocky Flats show that 95% of the time the winds are less than 18 mph, and the friction velocity would be less than 50 cm/s But the wind tunnel results are expressed for 95-mph winds and friction velocities of about 250 cm/s So at 95 mph the shearing stress is 25 times the 95th percentile values observed at Rocky Flats By extrapolation from the frequency distribution of winds observed at Rocky Flats I estimate that the likelihood of sustained 95-mph winds at Rocky Flats is just a few hours each year We have indeed chosen an extreme case	Any conservatism created though the use of the approach is accepted by the experimenters, given the application of the data toward RSAL development Because limited-reservoir soil erosion is a function of wind speed peaks, rather than average wind speed (as evidenced by the rapid decay in wind tunnel particulate concentration following each step change in wind speed), and because of differences in roughness length among test plots which limited peak centerline wind speed, the normalization of wind tunnel erosion potential to 95 mph is appropriate despite its conservative bias
13	In answer to Focus Group Question 8, regarding wind tunnel's ability to realistically and adequately account for vertical wind velocity The average vertical velocity at the ground surface is zero, both in the wind tunnel and outside the tunnel Only the variations (turbulence) in the vertical wind velocity are important, and the "typical" (root-mean-square) vertical variations are about the same as the friction velocity it is my opinion that at high speeds the high frequency turbulence would cause abnormal particle behavior on the soil surface, in that the oscillations of the particles would cause an over estimation of erosion potential	The reviewer's assertion that high-turbulence conditions created in the wind tunnel generate conservative estimates of erosion potential relative to "real world" conditions is consistent with the beliefs of the experimenters It is important to note that the vertical vector of wind sheer is consistently orders of magnitude smaller than the horizontal vector at Rocky Flats, based on horizontal and vertical wind speed data, and therefore has far less impact on soil erosion The rare occurrence of a meteorological event with a significant vertical component (e g , a dust devil) would be short-lived and of limited horizontal extent, and would therefore have very little impact on annualized exposure estimates such as those produced using RESRAD
14	In answer to Focus Group Question 9, regarding adequacy of wind tunnel to	It is the smaller scale turbulence that projects wind flow into direct contact with the erodible surface and

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	Review Comments – Wind Tunnel Reviewer #2	Response
	represent the effects of rapid fluctuations in wind speed, wind direction and turbulence The rapid fluctuations in wind speed are taken into account through the friction velocity in the wind tunnel The turbulence outside at Rocky Flats may be large, but we think of it as "gusts" that are large in scale (tens of meters) as compared to the wind tunnel where the turbulence is more like 0 01 meter in scale I can accept this turbulence scale difference because I believe that it leads to an over estimate of suspended dust	contributes to particle entrainment, as described in response to prior comments The well-developed boundary layer created within the wind tunnel generates significant small-scale shearing forces that may tend to liberate erodible material in a more effective manner than the natural erosive process
15	In answer to Focus Group Question 10, regarding effectiveness of wind tunnel in interacting with differently sized particles The particulates that are resuspended are rarely primary particles That is, they are clusters of many kinds and sizes of particles called aggregates The resistance to wind erosion thus depends on the strength of the aggregate bonding The wind tunnel provides sufficient shearing stress at the surface to suspend particle aggregates in the size ranges far greater than the respirable-size particles Redeposition [in the tunnel – ed] is negligible	Prior studies using the MRI reference wind tunnels, such as those that resulted in the EPA-recommended industrial wind erosion emission factors presented in *Compilation of Air Pollutant Emission Factors (AP-42)*, document the resuspension and capture of particle sizes on the order of 100 µm aerodynamic diameter in the wind tunnel effluent Particles of such size play a role in liberating finer particles through physical interaction with the soil surface but have insignificant direct impact on human exposure via the inhalation pathway
16	In answer to Focus Group Question 11, regarding the effectiveness of the wind tunnel at reproducing resuspension at different wind speeds for different particle sizes The wind tunnel does control wind speed and can thus be used to estimate erosion potential as a function of wind speed The wind tunnel provides a means of measuring the full range of wind speed effects on erosion potential These results are not subject to any limitation with respect to threshold debates So the data are very useful for determining Radioactive Soil Protection Levels regardless	The effects of wind speed steps on coarse and fine particle erosion are adequately quantified though the wind tunnel protocol, as noted by the reviewer If the wind tunnel protocol had serious limitations in duplicating the effects of differing wind speeds on the erosion of differently-sized particles, though such effects are not in evidence, then the normalization of data to 95 mph 10-m equivalent wind speed would mitigate any limitations related to lower wind speed effects
17	In answer to Focus Group Question 12, regarding appropriateness of particle sampling protocol There remains one discrepancy that the authors have not satisfactorily explained That is, the Dust TRACK unit which was calibrated with a standard dust (Arizona road dust) did not agree with the mass sampling train The main function of the DustTRACK was to provide real time particle	The operating principle of the DustTRAK is based on 90□ light scattering Light scattering (deflection) by local variations in refractive index is caused by the presence of particles whose size is comparable to the wavelength of the incident light The theoretical detection efficiency peaks at about 0 2-0 3 □m and decreases in a physically predictable manner for larger particle sizes

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	Review Comments – Wind Tunnel Reviewer #2	Response
	concentration data and this function was not seriously compromised by the data adjustments	The DustTRAK PM_{10} monitor was calibrated against the actual PM_{10} mass collected on the backup filter of the wind tunnel effluent sampling train during a given test run Calibration of the DustTRAK data against the PM_{10} filter mass eliminated the bias of the optical particle counter against larger particles (i e , particles approaching 10 □m aerodynamic diameter) This calibration required an integration of the real-time DustTRAK PM_{10} concentration profile (versus time) and calculation of the average DustTRAK PM_{10} concentration The average DustTRAK PM_{10} concentration was then compared to the average PM_{10} concentration calculated from the PM_{10} mass collected on the backup filter below the cyclone Use of the DustTRAK monitor provided a more comprehensive analysis of surface erodibility than wind tunnel effluent sampling alone This is particularly appropriate for surfaces that do not have a well-defined wind erosion threshold velocity
18	In answer to Focus Group Question 13, regarding the treatment of deposition and resuspension in the wind tunnel It is a safe bet that deposition (or, redeposition) is not occurring in the test section of the wind tunnel for reasons stated previously So particles are entering the sampling train that normally might be redeposited and held at a higher bonding energy The wind tunnel results would tend to over-predict erosion potential	The subtraction of background concentration eliminates the over-prediction that might be associated with ambient dust concentrations entering the wind tunnel, however, the saltation impacts of ambient dust on the soil surface may contribute to greater effluent dust concentrations than would be measured if natural deposition mechanisms were not overshadowed by the high winds generated within the tunnel Any lingering over-prediction is acceptable to the experimenters given the end use of the data
19	In answer to Focus Group Question 14, regarding methods used to verify sampling efficiency of the wind tunnel One of the best methods of verifying one type of sampling efficiency would be to used the wind tunnel on radioactively-labeled soil But of course that was done here, quite independently, during the investigations following the wildfire There are other types of verifications that could be done, but there is no indication that the tunnel is underestimating suspended mass because of some inefficiency problem In face, it is my opinion that the wind tunnel overestimates the erosion potential, see question 8	The post-wildfire wind tunnel studies clearly demonstrated that activity-enrichment of resuspended dust from contaminated soils is not occurring The post-wildfire study used Pu-239 as a radioactive tracer-of-opportunity and verified the effectiveness of the wind tunnel to collect erodible material from undisturbed and disturbed surfaces with specific activities that were consistent with the activities measured in the erodible layer of the underlying surface soils
20	In answer to Focus Group Question 15, regarding activity related intake by humans For all practical purposes the enhancement factor argument can be neglected at Rocky	Haines, et al , demonstrated in *Correlating Plutonium Activity in Fugitive Dust to Plutonium Concentration in Surface Soils at Rocky Flats, Colorado* (2001) that actinide contamination in surface soils will be

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	Review Comments – Wind Tunnel Reviewer #2	Response
	Flats as this data indicates ["data" are wildfire study data – ed]	resuspended by wind at a specific activity not exceeding the specific activity in the soil reservoir That is, actinide concentration in dust eroded from the contamination area east of 903 Pad is 1 1 or less compared to the actinide concentration in the soil reservoir No enrichment of actinide concentration through wind erosion was observed (in fact, dilution was observed in the PM_{10} particle size range, probably due to preceding deposition of diluting materials onto the contaminated soil surfaces)
21	In answer to Focus Group Question 16, regarding representativeness of increased air concentration determined by wind tunnel It is the opinion of this reviewer that the results are likely to be an overestimate of suspended dust and erosion potential compared to the worst that would ever be observed in nature Additional analysis of the data may be helpful, however	As stated throughout this response, study results that provide conservative inputs into RESRAD and the risk assessment to produce reasonably conservative RSALs are acceptable to the working group In the field studies performed, it is not reasonably possible to eliminate this bias
22	Response to "Evaluate if the wind tunnel results are being properly used in developing input values for application in the selected models Because of the extensive data available for screening level purposes, the resuspension factor used in risk assessments is recommended (NCRP 129, 1999) to decrease as t^{1} and this is in agreement with the wind tunnel observations at Rocky Flats In the Appendix A of the RSAL Task 3 Report, I saw that the air concentrations as well as the base erosion potential multiplier decrease as $t^{0\ 69}$ which is a confirmation that recovery from fire is not unlike the decrease in resuspension factors observed following Chernobyl We should all feel more confident that this is a unifying observation and in line with the NCRP recommendation for screening level risk assessments	The relative agreement of the Site-specific Rocky Flats resuspension factor to independently-developed resuspension studies performed at Chernobyl reinforces the experimenters' belief that the wind tunnel study results are representative of real processes The further agreement with NCRP recommendations should quell any lingering concerns with the applicability of these results to the intended purpose The fact that the post-fire erosion potential multiplier curve produced in this study is based on a very limited set of data suggests that its relative agreement with other studies would support implementation of the more theoretically based t^{1} dependence The analysts chose instead to use the more conservative empirical result
23	I am in complete agreement with the choice taken by the Task 3 working group authors to use the observed mass loading distributions for Rocky Flats as the site-specific data and preferred over any mass loading data inferred directly from the wind tunnel study The approach is much more realistic than other risk assessment approaches known to this reviewer for the case of fire effects	The working group has confidence in the quantity and quality of the local ambient particulate matter concentration data and modeling inferences used to develop the probabilistic mass loading distribution

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	Review Comments – Wind Tunnel Reviewer # 3	Response
	<u>General Comments</u>	
	No general comments require response	
	<u>Specific Comments</u>	
1	Report A [Wildfire Report – ed] uses 38 95% as the ratio of PM10 to total suspended particulate mass but Report B [Controlled Burn Report – ed] uses 50% Since 50% sounds like an approximation and 38 95 sounds like a measurement, I would suggest revising Report B with the 38 95%	Because the wildfire report examined the very low concentration of actinide in airborne dust particles and compared these to the actinide concentration in the soil from which the dust was eroded, it was critical to the accuracy of the ambient background correction that the PM10 to TSP ratio be known Therefore, Colorado Department of Public Health and Environment data from ambient air particulate matter samplers located within several hundred yards of the wildfire area were queried and the average PM_{10} TSP ratio for the area determined to be 0 3895 For the controlled burn data correction, where the results were used to develop post-fire erosion potential multipliers based on comparisons of erosion from adjacent burned and unburned plots, an estimate of the background correction was sufficient As the following sensitivity analysis shows, the error introduced by assuming a PM_{10} TSP ratio of 50% was small <u>Test Run CB-7 (from Appendix D)</u> Wind-tunnel PM_{10} net mass 9 15 mg Background net mass 8 49 mg Estimated (50%) PM_{10} background mass 4 24 mg Calculated (38 95%) PM_{10} background mass 3 31 mg PM_{10} erosion potential (50% ratio) 0 12 g/m2 PM_{10} erosion potential (38 95% ratio) 0 14 g/m2 The calculated (38 95%) correction would result in a net growth in PM_{10} erosion potential for both burned and unburned plots However, because the end use of the data is to develop a post-fire mass-loading multiplier by calculating the ratio of burned to unburned plot results, the same PM_{10} correction is applied in the numerator and the denominator of the multiplier Since the denominator is a smaller erosion potential (unburned) than the numerator (burned), a decrease in the PM_{10} correction, as reflected here, will result in a smaller post-fire multiplier By using the estimated PM_{10} background correction, the multiplier used in the RSAL calculations is larger than it should

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	Review Comments – Wind Tunnel Reviewer # 3	Response
		be, hence is conservative
2	I got confused with the discussion of the mass collected, until I came to the realization that mass collected by the cyclone doesn't have PM10 I think that some rewriting of this section should be done to prevent people like me from getting confused There is no problem with Report B where isokinetic sampling was done	This comment will be noted to the authors of the original report
3	Tests were run until the end of soil movement I think it would be informative to compare the times needed for the end of soil movement for the different locations	Such a comparison would be complicated by differences in roughness length between locations It was the observation of the experimenters that roughness length (which limits peak centerline wind speed) increased as vegetation recovered over time The increase in roughness length was more likely to have driven differences in time required to achieve complete collection of available erodible material than test plot geography, given that all plots were collocated atop a common soil type and geologic unit of relatively level elevation
4	(Trivial) The last line of page D-6 should have 0 0022945 pCi/cubic meter	The reviewer's comment is noted The example calculations were copied into document format from spreadsheets, so background rounding of multiple-place decimal values may create the appearance of minor errors
5	These assumed values may or may not be correct, but the curve is dominated by the assumptions, not by experimental data The multipliers should be labeled as "assumed post-fire erosion potential multipliers "	The reviewer's use of the word "assumed" to describe the post-fire erosion potential multiplier curves is acknowledged However, in the case of the spring fire curve, the return of erosion potential to its ground state (pre-fire conditions) has been observed in the prescribed burn plot and is not an assumption Therefore, the zero values that dominate the spring fire multiplier curve-beginning month 13 are not assumed The fall multiplier curve is certainly less well characterized, and depends on the assumption that a fall post-fire multiplier curve (as a function of the vegetative recovery rate) has a shape similar to the spring curve, but this assumption is supported by local ecologists See the response to Comment 10 from Peer Reviewer 1 for additional discussion
6	Addressing FG Q1 The scientists and equipment have a long history of quality work in measuring fluxes of particles emitted by wind erosion	The fact that this equipment was used to develop emission factors for industrial wind erosion (presented in US EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*) was considered an endorsement of the technique for the given application
7	FG Q2 The pitot tube methodology is adequate for characterizing the wind profile since fast-response anemometry is not	The pitot tube method has two primary qualities recommending it for this application

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	Review Comments – Wind Tunnel Reviewer # 3	Response
	needed	• It is an EPA reference test method for determining air velocity in ducts, and • It is sufficiently rugged for the application (i e , it will not be compromised by particle impacts or contact with the ground
8	FG Q3 One must consider that the results are relative to the length of the wind tunnel and that the work done was self-consistent under the conditions that are described in the methodology That is, I think that no portable wind tunnel would exactly duplicate all possible fetch effects, but that some wind tunnel had to be used and that this wind tunnel is probably as good as most would be relative to the fetch effect	It is true that small amounts of erodible material may be sheltered by surface roughness elements from the entraining energy of the wind tunnel when a predominant wind direction exists However, the boundary layer flow generated at soil level is not uni-directional, but is accompanied by turbulent eddies and wakes created through wind interaction with surface elements This turbulence reduces the sheltering effect of surface irregularities, as observed by the experimenters
9	FG Q4 This wind tunnel adequately accounts for small-scale variations in surface cover and surface roughness It does not account for large-scale or middle-scale variations, however	As presented by Peer Reviewer 2 and stated repeatedly in response to comments, the small-scale turbulence created in the wind tunnel boundary layer (in lieu of large-scale shearing forces) appears to have produced conservative post-fire mass loading enrichment factors for use in RESRAD and risk analyses Therefore, given the end use of the data, the limitations of the wind tunnel to reproduce natural, large-scale wind effects are minimal and likely resulted in higher than actual erosion potentials for prevailing conditions at Rocky Flats
10	FG Q5 Roughness can act to dam or retard rather than release particles This happens in nature too Consequently, I think that this phenomenon is adequately modeled in a wind tunnel	The experimenters agree that the presence of roughness elements is essential to the development of representative measurements of erosion potential Variability in roughness element size between test plots required replicate tests to provide satisfactory statistics, which was accomplished
11	FG Q6 I assume that the DustTRACK instruments were used to measure when the dust concentration returned to the level from which it started before wind erosion started Therefore, I assume that the sampling periods were adequate	The reviewer's assumption is accurate, as evidenced by Figure 3 of the controlled burn report
12	FG Q7 The wind tunnel was designed to reproduce conditions near the ground during high winds From tests of the wind tunnel for other locations, this tunnel is well suited for this job	The boundary layer developed in the wind tunnel generates wind shear stress that mimics or exceeds the erosive force of natural winds of the same magnitude
13	FG Q8 Vertical wind variations are modeled well with the wind tunnel See Question 9	It is important to note also that the vertical vector of wind sheer is consistently orders of magnitude smaller than the horizontal vector at Rocky Flats, based on historic horizontal and vertical wind speed data, and therefore has far less potential impact on soil erosion

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	Review Comments – Wind Tunnel Reviewer # 3	Response
		The rare occurrence of a meteorological event with a significant vertical component (e g , a dust devil) would be short-lived and of limited horizontal extent and would therefore have very little impact on annualized exposure estimates such as those produced using RESRAD
14	FG Q9 In wind tunnels, the flux of momentum is carried by smaller-scale fluctuation than in outdoor work However, one gets the same results by comparing resuspension for the same friction velocity in a wind tunnel or outdoors experimentation That is, for the same friction velocity (momentum flux) you get the same resuspension, even though the turbulent spectrum is different for outdoor and wind-tunnel winds	The large-scale components of wind turbulence have little overall effect on wind erosion, only the small-scale turbulence and resultant sheer stress is effective at penetrating surface roughness elements and dislodging particles that ultimately contribute to the soil flux These small-scale components are more influenced by surface roughness than would be large-scale components As was stated by Peer Reviewers 2 and 3, the inability of the wind tunnel to mimic large-scale turbulence has little or no affect on its ability to produce small-scale turbulence within the surface boundary layer, causing wind erosion of the available particle reservoir at a representative or even conservative rate
15	FG Q10 See answer 9 above For the resuspension of PM10, the dominant mechanism is the sandblasting of the surface by particles larger than 100 micrometers	The influx of ambient dust into the wind tunnel, combined with the resuspension of larger aggregate from the soil reservoir as wind speeds increased, provided sufficient quantity of larger particles to initiate saltation and liberate PM_{10} The subtraction of background concentrations of TSP and PM_{10} from wind tunnel effluent concentrations accounted for the net numerical influence of incoming, saltating particles without allowing their presence to bias the erosion potential measurement of the test plot itself
16	FG Q11 Yes, wind tunnels and outdoor experimentation give consistent threshold friction velocities for different particle sizes	If the wind tunnel protocol had serious limitations in duplicating the effects of differing wind speeds on erosion of differently-sized particles, of which there is no evidence, then the normalization of data to 95 mph wind speed would mitigate any limitations for a given wind speed
17	FG Q12 Non-isokinetic flow is corrected for in the report	Representative samples for all particle sizes of interest were obtained through isokinetic sampling and, when isokinetic conditions could not be maintained during the wildfire tests, through correction of results to account for potential non-isokinetic bias
18	FG Q13 The wind tunnel results give a net flux for the area sampled by the wind tunnel For the scale involved, however, the wind tunnel test is adequate	The experimenters agree that the net erosion potential is measured on plots that are small in scale relative to the area of the fire However, the approach is adequate given the number of replicate test runs and the conservative nature of the resulting data analysis
19	FG Q14 See answers to above questions	No additional comment is offered
20	FG Q15 Activity or dust concentration	Haines, et al , demonstrated in *Correlating Plutonium*

	Review Comments – Wind Tunnel Reviewer # 3	Response
	increases with wind speed and this is shown in the data	*Activity in Fugitive Dust to Plutonium Concentration in Surface Soils at Rocky Flats, Colorado* (2001) that actinide contamination in surface soils will be resuspended by wind at a specific activity not exceeding the specific activity in the soil reservoir That is, actinide concentration in dust eroded from the contamination area east of 903 Pad is 1 1 or less compared to the actinide concentration in the soil reservoir No activity enrichment of actinide concentration through wind erosion was observed (in fact, dilution was observed in the PM_{10} particle size range, probably due to preceding deposition of diluting materials onto the contaminated soil surfaces)
21	FG Q16 Yes, increases in air concentrations associated with increasing wind speeds are reasonable	No additional comment is offered

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	Review Comments – Reviewer 1	Response
	General Comments	
1	"The decision structure and the nature of the information used have not been made sufficiently clear in the presentation" Reviewer thinks report needs more discussion of its context How RSALs are used as one of a number of hazard management tools Reviewer thinks the concepts involved in setting an RSAL need to be specifically discussed in the report Reviewer thinks report needs a clearly articulated approach to the treatment of uncertainties Reviewer thinks report needs a clear approach to the treatment of differences between people (variability) Acknowledge historical difficulties such as history of public distrust in the text in an effort to develop a credible basis for planning What is an RSAL? Why does Rocky Flats need them? What were the previous efforts at developing RSALs and why might they change? How will a RSAL be used? (two uses to decide where the surface can be left alone, and as one input in deciding the degree of cleanup required) How do RSALs work with other hazard management tools? (Important that everyone understand that RSALs are not the only tool) What are the uses and limits of science in developing an RSAL? What is the risk? What is the dose? What are the circumstances for which risks or doses should be estimated? How are differences between people treated?	Task One of the RSAL Report and Attachment 5 of the Rocky Flats Cleanup Agreement, called the Action Level Framework, describes the regulatory approach for the establishment of an RSAL

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	Review Comments – Reviewer 1	Response
	How are uncertainties accounted for? What is a "reasonably maximum exposed (RME) person? Why do you need scenarios? How do you choose them?	
2	Reviewer wants more transparent explanation of what the science says and doesn't say, what is uncertain, what are alternative possibilities, and what choices the managers have for dealing with uncertainty Uncertainties important to setting RSALs need to be presented in a clear, informative way to both managers and concerned parties	As stated at the end of Section V, we agree that it is important to convey the uncertainties in the available information to risk managers Section VI discusses the general approach to quantifying variability and uncertainty, and Table VI-1 summarizes the effect that sources of uncertainty may have on dose and risk estimates The Appendices provide a more detailed description of the alternative approaches that were available to specify probability distributions to characterize variability In order to improve the clarity of the presentation of potential impacts of uncertainty, Section VI will be expanded to include the following (1) paragraph on how uncertainty was considered when defining probability distributions to characterize variability (PDFv), (2) an overview of the information gained from the sensitivity analysis, and (3) the collective impact of the uncertainties in setting RSALs for each exposure scenario In addition, a semi-quantitative ranking of the level of confidence (i e , low, medium, high) in the PDFv for each input variable will be added to the Appendix *Section 6 is now Section 7, and Table structure differs*
3	A clearer framework for addressing uncertainties will lead the authors to revisit their discussion of certain key parameters in their model which cause significant uncertainty in the dose and risk levels, the most notable of these are "mass loading", "soil ingestion rates" the EPA dose and risk estimators These issues should be addressed up-front, at the beginning A discussion of the strategy and context of the RSALs should be included up-front, right at the beginning This would increase the clarity of the presentation a) Obligation to acknowledge the uncertainty in a value that is supposed to represent a given percentile of behavior	We agree that a more comprehensive summary of the uncertainties in the assessment can be added to Section VI and the Appendices See response to previous question The comment is unclear The probability distributions used to characterize variability are selected with the intent of describing the full range of percentiles Point estimates are generally selected to characterize the RME individual, which is consistent with EPA guidance If the suggestion is to note how the point estimate corresponds with a percentile of the probability distribution for a given input variable, this information can be presented Often a point estimate is used when there is insufficient information to justify selecting a probability distribution – in such cases, it would not be possible to identify the percentile represented by the point estimate Appendix A, page 19, Section (ii), discusses the rationale for selecting an upper bound of 1,000 mg/day for the soil ingestion rate distribution for

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	Review Comments – Reviewer 1	Response
	b) Choice not to include pica child in the child soil ingestion distribution should have more justification c) Variability in dose and risk factors requires more discussion	children The choice reflects an interpretation of the available data on soil pica behavior that suggests most children will exhibit day-to-day spikes in ingestion rate, but the long-term average is likely to be much lower The literature suggests that soil pica behavior is an example of an acute exposure scenario, which may be of concern for some acutely toxic chemicals This acute exposure potential is already being addressed in the Industrial Area and Buffer Zone sampling plans by the hot spot methodology In a chronic exposure scenario, which the RSALs are developed for, we are concerned with long-term average soil ingestion rates The selection of 1,000 mg/day is considered to be conservative (health protective) upper bound for the population Appendix A provides detailed discussions of the variability in factors used to quantify dose and risk Also see response to comment #8 from this same reviewer *Section 6 is now Section 7, and Table structure differs*
4	Reviewer believes that even in a qualitative uncertainty analysis, "one would like some sort of statement of confidence" about how likely the risk estimate is not likely to be exceeded using that choice of parameter The Reviewer gave an example of categorizing uncertainty into 4 groups a) a best estimate, b) an unspecified degree of confidence (some added conservatism), c) high confidence, and d) very high confidence that future information will be consistent with the estimate	We agree that it would be useful to assign a semi-quantitative ranking of confidence in the probability distribution for variability for each factor discussed in Appendix A This information can be used to expand the Section VI discussion of the confidence in the corresponding risk distribution, based on knowledge of the important sources of variability from the sensitivity analysis A three-tier ranking system will be used to reflect level of confidence (i e , low, medium, and high) *Section 6 is now Section 7, and Table structure differs*
5	Reviewer urges agencies to use "high confidence" values for developing the RSAL, rather than the "best estimate" or "conservative estimate of unspecified degree" values that largely were used, in order to increase the robustness of the choice	The comment appears to reflect a preference to use different words to describe the point estimates and probability distributions selected for the RSAL calculations We agree that it is desirable to use "high confidence" values when they are available The intent of the discussion of uncertainty in Section VI and Appendix A is to present the information on uncertainty *Section 6 is now Section 7, and Table structure differs*
6	Reviewer thinks it would be useful to include a direct quantitative comparison of the newly selected RSALs with previous values, and why there are differences, if any Doing this will help understanding and indicate the robustness of the selection	There are substantial differences with the approach used in these calculations as compared with approaches used in the establishment of RSALs in 1996, and with the recommended values as calculated by RAC in 2000 The differences between the current effort and that performed in 1996 are that the current effort

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	Review Comments – Reviewer 1	Response
		- Uses probabilistic methodology - Accounts for the elevated concentrations of contaminants in air that would result from periodic grass fires - Calculates risk in addition to dose - Considers two additional exposure scenarios Wildlife Refuge Worker and Resident The two most important ways in which the current effort differs from the work performed by RAC are in how it addresses grass fires, and in the choice of exposure scenario the RAC modeled a very conservative Resident Rancher scenario The current effort also calculates risk directly whereas RAC calculated risk indirectly The agencies do not intend to retain the RSALs that are currently in the Action Level Framework of RFCA The agencies do not feel that the effort to prepare a robust quantitative comparison of the parameters used in the calculations over the past six years is warranted The authors of the Task 3 Report have presented tables and discussion that allow the interested reader to compare the inputs and results of the 1996 and present RSAL calculations, and to better understand the bases for the group's parameter selections in the present work Detailed information about how the Agencies address the fire issue and how that differs from the RAC methodology is given in Appendix G
7	The discussions of various uncertainties need to be synthesized (integrated?) "so as to provide a reasonably transparent description of how using any particular calculated value for a RSAL represents taking a position with respect to the underlying uncertainties" Key uncertain parameters that would have a substantial impact on the RSALs, if changed, should be identified	This comment will be addressed by expanding the discussion of uncertainties in Section VI, as described in response to Comment #2 above **Section 6 is now Section 7*
8	Reviewer wants a) greater discussion of uncertainty and variability in ICRP 72 dose coefficients and FGR 13 risk coefficients, b) quantitation of confidence level in coefficients selected, c) consideration of selection of dose and risk coefficients appropriate for an RME individual	a) Chapter VI is being rewritten to include a greater discussion of, among other things, sources of uncertainty in dose and risk coefficients The discussion will include the excellent list of sources of uncertainty and variability contained in Appendix D of Federal Guidance Document 13, relative to the estimate of risk coefficients Since most of the same sources of uncertainty affect the estimates of dose coefficients, this discussion will suffice for the ICRP 72 dose coefficients used in the Task 3 computations as well This discussion will remain qualitative only

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	Review Comments – Reviewer 1	Response
		at this time It is noteworthy that even the ICRP, whose work forms the basis of the dose and risk coefficients used in this Task, has not made a quantitative estimate of uncertainty relative to their recommendations Sources of uncertainty which will be discussed in the rewrite include Uncertainties in the structure of biokinetic models Model of the respiratory tract Gastrointestinal tract model and f1 values Uncertainties in information used to construct biokinetic models for plutonium Direct information on humans Information on humans from chemically similar elements Direct information on non-human species Information on animals from chemically similar elements Uncertainties in interspecies extrapolation Uncertainties in inter-element extrapolation Uncertainties in central estimates stemming from variability of human populations b) The working group feels that it is not possible at this time to quantify the confidence interval of the dose and risk coefficients selected (which are as listed in ICRP 72 and FGR 13), although quantification of uncertainty may be possible in the not distant future EPA's Office of Radiation and Indoor Air (ORIA) is currently tasked with making estimates of uncertainty in the FGR 13 risk coefficients, which is a pioneering effort for a regulatory/guidance agency The work by the Risk Assessment Corporation that this reviewer has cited as a starting point will be considered by ORIA in its task The working group will incorporate the results of ORIA's work in an Addendum to this Task, if it is felt necessary to revise the dose or risk coefficients recommended by ICRP 72 and FGR 13, in the light of ORIA's work This is not to dismiss the Reviewer's concern, which is legitimate At this time the working group believes that it has made several prudent decisions in the selection of dose and risk coefficients which argue in the direction of reduced uncertainty The choice of ICRP 72 ingestion dose coefficients for plutonium over those of ICRP 30 results in a defacto selection of an absorption fraction (f1) some 50 times higher than the f1 value associated with plutonium oxides (used by the working group in 1996)

	Review Comments – Reviewer 1	Response
		Although the FGR 13 still estimates the uncertainty in the f1 value for plutonium to be on the order of a factor of 5, this is an improvement over ICRP 30 and significantly increases the importance of the soil ingestion pathway The choice of the M absorption type over the less conservative S absorption type for the plutonium inhalation dose and risk coefficients represents a prudent choice in the face of uncertainty in the chemical and physical form of the plutonium in the environment, and represents the majority of the working group's position that there is uncertainty in the degree of oxidation of the plutonium from the 903 Pad spill, and the size and nature of soil particles to which it is attached (The DOE disagrees, and believes that this uncertainty is low, and that the S absorption type, appropriate for a pure plutonium dioxide should have been used) In response to the comments of other reviewers, a more complete discussion of the basis for selection of the M absorption type will be included in the revised Task 3 Report The choice of ICRP 72/FGR 13 coefficients represents a move toward the most complete, and accurate biokinetic models, with a corresponding reduction in uncertainty c) As to the selection of a special dose or risk coefficient pertinent to the RME individual, the working group believes that this goes outside the boundaries of the RME concept and should not be done "Exposure" as used in the Task 3 Report means the combination of external radiation exposure and internal intake of radionuclides (this concept originates from the more general Superfund context of exposure to hazardous materials, and may not appear to be consistent with exposure as it is used in the field of Health Physics) Reasonable Maximum Exposure means that the combination of scenario features and input parameters that affect exposure (exposure conditions) are considered collectively at their reasonably maximum values – for example the 95th percentile of the cumulative probability distribution RME does not include conversion to dose or risk – to do so would be to introduce additional conservatism or consideration of human variability into the RME concept The consideration of uncertainty in dose and risk coefficients is best kept separate

	Review Comments – Reviewer 1	Response
		**Section 6 is now Section 7*
9	Reviewer believes uncertainty and variability of ICRP and EPA dose and risk coefficients should be discussed	See response to comment #8 above
10	Reviewer believes the discussion of the sensitivity analysis is "not always helpful or balanced" He believes that the sensitivity analysis together with what is known about the uncertainty in various processes should be used to identify the key uncertainties that will impact the selection of a RSAL"	Section VI will be expanded to include a discussion of how the sensitivity analysis was used to identify the key exposure pathways and variables This discussion will be tied to the information presented on uncertainty in each point estimate or probability distribution selected for the input variables **Section 6 is now Section 7*

	Review Comments – Reviewer 2	Response
1	Paragraph 2 of Overall Summary Validity of backward calculation method because this method "ignores potential correlations between risk or dose and input variables"	Correlations among exposure variables used to estimate dose or risk are a source of uncertainty in Monte Carlo simulations In this risk assessment, no information was identified to correlate input variables The fact that input variables were treated as independent in the Monte Carlo simulation does introduce uncertainty into the resulting risk distribution for forward calculations, and RSAL distribution for back calculations However, we disagree that it somehow invalidates the back calculation approach
2	Paragraph 3 of Overall Summary Inadequate statement of purpose of the probabilistic analysis, up-front Definition must go beyond a simple determination of a range of outcomes because "the distributions have to be determined in a consistent manner with the overall purpose "	The difference between point estimate and probabilistic approaches is first described in Section II, page 4 Further discussion of the goals of probabilistic risk assessment (PRA) is given in Section VI The report consistently emphasizes that the purpose of the PRA is to quantify variability in risk or RSAL based on variability in exposure, using probability distributions for inputs There is no reference to providing a "range of outcomes" **Section 6 is now Section 7*
3	Paragraph 4 of Overall Summary "Interjection of bias by the working group by refusing to assign distributions for variables with sparse data, and using, instead, <u>point estimates</u>	As explained in Section IV-4 of the report, it may not be appropriate to develop probability distributions for all parameters For some variables, the existing studies may contain serious design flaws, may not be representative of the site population, or may have an inadequate number of study subjects The result is lack of confidence in the ability of a distribution to represent the site population In these situations, a point estimate may be selected to represent a particular variable If the variable is known to be influential, (per the sensitivity analysis) the use of a point estimate can bias the outcome For example, if the point estimate is a high-end value, the distribution of risk may be right-shifted (e g , it is biased in the conservative direction) In situations such as this, it is important that the risk assessor communicate to the decision makers the consequences of this choice Section VI will be revised to qualitatively communicate the uncertainty and/or bias in the selection of each variable and its impact on the outcome **Section 6 is now Section 7*
4	Paragraph 5 of Overall Summary	Section VI will be expanded to provide a clearer

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	Confusing presentation of uncertainty discussion in Section VI Lack of separation between variability and uncertainty, Unclear labeling of particular distributions as representing variability or uncertainty (Column 2 in Tables VI-2 to VI-5)	distinction between variability and uncertainty, and to reiterate the concept that selections of probability distributions for variability are a source of uncertainty Column 2 will be removed from Table VI **Section 6 is now Section 7*
5	Paragraph 6 of Overall Summary Applicability of cancer risk factors taken from Federal Guidance 13, which are derived for mixed age group populations, to single age groups, such as populations that are only adults	We agree with the reviewer We will revise the report to use adult-specific cancer slope factors when appropriate
6	Paragraph 7 of Overall Summary Quality of presentation Wrong fonts for symbols in equations References in the text are inconsistent with Table headings Tables presented in difficult to read format Failure to present some important parameter values, e g , the cancer slope factors referred to on p 46 Reference list has mixture of citation styles	The typographical errors will be corrected
7	The reviewer had issues related to a) improper modeling, b) mixing of variability and uncertainty, and c) assigning biased point estimates in lieu of distributions all generally lead to overly conservative conclusions Reviewer could not tell whether the computed RSALs are appropriate, legitimate, or useful, since the reviewer could not determine the degree of bias in the calculations	a) As discussed in the response to Comment 1 from this reviewer, we disagree that the back calculation method used in the modeling done to calculate dose and risk-based RSALs was proper The working group was aware of the limitations of the back calculation method in calculating the RSALs However, the Monte Carlo simulations were run with the assumption of independence among input variables because no information was identified to specify correlations Moreover, both the concentration term and the risk were characterized by point estimates rather than distributions Both of these conditions satisfy the criteria under which back calculation is a valid approach (Burmaster et al , 1995, Ferson, 1996, Bowers, 1998, as referenced in the text) b) As discussed in the response to Comment 4 from this reviewer, Section VI will be revised, as necessary, to differentiate more clearly between uncertainty and variability c) Finally, conservative default values recommended by EPA for calculating RME exposures were used as point estimate values when the incompleteness of the

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		available data precluded much confidence in any distributions The working group decided on this conservatism deliberately, in order to be health-protective Our rationale is discussed further in the response to Comments 3 & 8 from this reviewer As mentioned above, the purpose of Section VI is to qualitatively communicate the uncertainty and/or bias in the selection of each variable and its impact on the outcome It will be revised to more clearly describe, qualitatively, the uncertainty and/or bias inherent in the choices made **Section 6 is now Section 7*
8	Paragraph 9 of Overall Summary The working group should "add some expertise to their group and compute new values of the RSALs in a way that is state-of-the-art and credible to the entire scientific community" This work would be rejected for publication	The work of this group is based on sound scientific principles and has been performed by professionals well grounded in their disciplines The staff tasked with working on the calculation of RSALS consider their audience to be the stakeholders involved with the Rocky Flats cleanup and the RFCA parties The agencies recognize that although an attempt was made to be objective in the selection and calculation of the modeling input parameters, there was bias in the process This bias was based on recognition of community preferences and input as well as a conscious choice to err on the side of conservatism when there was uncertainty This reviewer, as well as others, have pointed out that some of the parameters were overly conservative The working group believes that it generally employed the appropriate amount of conservatism in light of the uncertainties surrounding certain parameters
9	Sensitivity analysis problems Reviewer appears to have understood that the sensitivity analyses for dose and for risk were both performed using Crystal Ball Text needs to be revised to make it clear exactly how RESRAD was used to perform the sensitivity analysis	RESRAD was used to perform the sensitivity calculations and generate the tables and figures shown in the Task 3 report The text will be revised to clarify the use of RESRAD for this purpose
10	Text refers to Fig IV-4 (2nd paragraph, p 27), but the figure is labeled Fig IV-5 Figure IV-4 is missing	Figures are numbered incorrectly, text will be corrected
11	Addition of 'mass loading for inhalation' parameter to the most sensitive list should not have been done because of "interest" in this parameter since the addition of ad hoc parameters is not objective or based on sound scientific principles	It is true that mass loading for inhalation is not as sensitive of a parameter as were some of the others In addition to the interest of the community in this parameter, there was general agreement among the working group members that this parameter required special consideration because of the possible effects

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		of a prairie fire and their potentially significant contribution to overall dose to the receptor Furthermore, the independent RSAL review performed by RAC identified the inhalation pathway as the most important contributor to dose
12	Sensitivity analysis problems Impact of using crudely estimated probability distributions on the sensitivity analysis Reviewer questions why final probability distributions were not used in the first place in the sensitivity analysis	The working group feels that the reviewer has misinterpreted the text The sensitivity analysis as described in Section IV-1 of the report used a ratio method based on *point values* to find the most influential variables Once determined, the process of developing distributions for those variables began The distributions were used in the RSAL calculations, they were not used in a sensitivity analysis
13	Reviewer points out that by choosing a conservative quantile of the output distribution to define a "reasonably maximally exposed individual", the cleanup costs, including those to the environment will be greater	As stated above in comment number 8, this reviewer, as well as others, has commented that some of the parameters were overly conservative The working group believes it has selected the appropriate level of conservatism given the uncertainty of certain parameters The agencies do not believe it is appropriate to consider the cost of cleanup or the extent of environmental damage that could result from cleanup while performing a risk assessment However, these factors will weigh heavily in the risk management decisions
14	Bias is interjected when point estimates are used instead of all probability distributions Reviewer thought the Open Space and Office Worker scenarios should have been done probabilistically too, and that a more complete explanation should have been given as to why this was not done	We agree with the reviewer that a probabilistic assessment of the office worker and open space user would have made for a more complete report The working group had four exposure scenarios, each having hundreds of parameters It takes time and resources to develop distributions for each of those parameters in each scenario The working group made a decision to focus not only on the parameters that were most influential but also on the exposure scenarios that would most influence the remedial decision Given that the agencies don't believe either Open Space or Office Worker scenarios will play an important role in the decisions on action levels and cleanup levels, this additional work will not be undertaken
15	Little or no attention was given to whether the contamination in soil is uniform enough (on a micro-scale) to be adequately described by a single concentration value Reviewer supplied a graphic to support his point Reviewer believes any impacts of non-uniform contamination in soil on sampling, on	The premise of hot particles of plutonium metal is likely to be more of a concern in the case of weapons accidents or intentional dispersion of plutonium, e g safety shots The contamination scenario at Rocky Flats is quite different The working group did consider the distribution of the plutonium contamination in the soils at the Site While the data

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	ingestion and on long-term risk calculations need to be addressed	are somewhat limited, and subject to interpretation, data collected near the 903 Pad, in air, indicate a plutonium activity distribution that is proportional to the mass of the airborne soil-derived particulate matter, for a number of different airborne particle sizes (several partitions were examined including particles from submicron to greater than 10 microns in size) These data suggest that the plutonium particles are attached to small soil particles, which in turn make up a soil matrix that becomes airborne as aggregated particles of different sizes If, instead, the contamination were attached to solid soil particles of substantially different sizes, the airborne contaminant distribution would show a characteristic proportionality to the area of the airborne particle distribution, and the specific activity would decrease with increasing particle size This was not observed The working group appreciates the perspective brought to this issue by this reviewer The working group did not consider the contaminant distribution for the purpose of understanding the dynamics of soil ingestion in the body It was instead concerned about the relative distribution of contamination in fine soils subject to inhalation, compared to the contaminant distribution in a larger range of airborne soil-particle sizes subject to deposition on plants and the subsequent ingestion of this deposited contamination The graphic provided by the reviewer would be somewhat modified in consideration of this new information, and would show reduced overall sensitivity to particle size, assuming the agglomerates would break up in the food preparation and digestive process in some predictable way The working group recognizes, along with this reviewer, that the exposure calculated for ingestion is conservative The relatively high amounts of contamination that are assumed to become airborne and subject to deposition, and the fractions assumed to remain with the plant material through the food preparation process suggest an overestimate of the ingestion dose and risk Any reduction in exposure due to particle size/absorption interactions can only increase this conservatism
16	Confusing presentation of uncertainty discussion in Section VI Expand uncertainty discussion of proper absorption category (M or S) for dose conversion factors to show that the	The Report will be revised to include additional information used in the decision to select type M, and its implications to uncertainty, as suggested In essence, the differences between agencies centered

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	different agencies held different beliefs	around the degree of uncertainty in the chemical and physical form of the plutonium in the environment around Rocky Flats DOE believes that there is high confidence that the plutonium in the environment is present as pure plutonium dioxide, for which the absorption type S is the appropriate choice The other agencies did not hold such high confidence of complete oxidation of the plutonium released to the environment, and also admitted the possibility of additional confounding factors such as attachment to small soil particles, for which absorption from the lung to the blood may be influenced by the rate of dissolution of the soil matrix as well as the chemical form of the plutonium ICRP Publication 71 provides the result of new studies, done since the publication of ICRP 30 which show greater variability in the absorption behavior of plutonium under environmental (as opposed to workplace) conditions, describes a number of chemical and physical complicating factors, and advocates the selection of type M, as a measure of prudence, in the absence of site specific information Although there is limited site specific information at Rocky Flats which indicates that plutonium dioxide is present under the 903 Pad, the majority of members of the working group felt that there was uncertainty in the degree of oxidation across the entire site, and the presence or absence of other complicating factors, and that it was therefore prudent to select type M for use in dose and risk calculations in this Task **Section 6 is now Section 7*
17	Wrong number of significant digits expressed in the americium plutonium activity ratio	The activity ratio used in the draft report compares HPGe gamma measurements for Am (reported to one decimal place) to alpha spectroscopy results for Pu (reported to four decimal places) This ratio will be replaced with an activity ratio, which compares alpha spectroscopy results for both elements The activity ratio used to re-calculate the sum-of-ratio values will be rounded to 0 17 **The 0 17 value was changed to 0 18 to reflect maximum ingrowth in weapons grade plutonium*
18	Decision to use 0 4 instead of 0 8 as a building shielding factor was a good one	It is likely that the selection of 0 4 was overly conservative, given the low energy photons from americium and plutonium that are addressed in this calculation The Technical Background Document for the Soil Screening Guidance for Radionuclides describes the decision to revisit the default GSF of 0 7 and change it to 0 4 Essentially this revision

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		addresses the fact that earlier in-home measurement studies did not account for the fraction of exposure due to cosmic and building material sources The revision appears to be based upon terrestrial and contaminant photons of intermediate energy, however, suggesting that it is conservative in the case of 60 keV photons The working group's decision to use the new default was based on the TBD revision and also on the fact that external exposure contributes little to the overall dose/risk
19	Decision that erosion potential quickly decreases after a fire is reasonable The decision that drought could occur 20% of the time also is realistic	We appreciate this reviewer's comment It was gratifying to the working group that the data from the wind tunnel experiments supported the intuitive observations of the individuals within the RSAL working group regarding the resuspension of contaminated soils from within vegetated cover of increasing density The drought frequency was guided by site-specific data and the insight gained from literature provided by the National Drought Mitigation Center's website
20	Discussion regarding the soil ingestion rate was too long, given the weaknesses in the data	We agree that the discussion of the soil ingestion rate variable is long relative to that of other variables However, the sensitivity analysis highlights this variable as being an important factor in the risk estimates In addition, there is considerable discussion in the scientific community on the appropriate methodology for incorporating available study data into risk assessments for both children and adults
21	NCRP Publication 129, "Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-specific Studies" should have been referenced and utilized in this Task	The applicability of NCRP 129 to the computation of RSALs was considered early in the working group's process Page 8 of NCRP 129 states that "It is again emphasized that the guidance proposed in this Report is for use in screening and is not intended for use as cleanup criteria, since the conservative nature of the guidance given here could result in greater amounts of soil being removed than would be necessary with *realistic, site-specific calculations* " Moreover, the comparison with EPA and NRC appears on page 8 "However, the limits proposed by NRC and EPA, *which are intended for cleanup* of contaminated sites are *based on the median dose to an individual in the most critically exposed population* rather than the *maximum dose to any individual* as used in this Report " (emphasis added) This statement leads one to expect that the NCRP screening levels, computed for generic sites will be much more conservative (and possibly much less

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		realistic), than those computed using the EPA methodology Owing to the fact that the computational basis of screening levels in NCRP 129 and in the Soil Screening Guidance used by EPA is different, and to the fact that NCRP 129 is not applicable to deriving cleanup levels, whereas the EPA SSG is routinely used in Superfund to derive preliminary remediation goals, the working group opted to exclude NCRP 129 from consideration
22	Central tendency values for children were reasonable However, the reviewer was "skeptical of how long the maximum consumption value (1,000 mg/d) might actually be sustained by a child"	We agree with the reviewer that the selection of an upper truncation limit of 1,000 mg/day is very high, and acknowledge that the intent is to be protective As stated in Appendix A (p 23), it corresponds with the 99 8th percentile of the lognormal distribution fit to the data presented as long-term average values The choice of the truncation limit reflects professional judgment that weighs the confidence in the empirical data (i e , medium), the skewness of the probability distribution (meaning the relationship between the standard deviation and mean, which in this case the CV = SD/mean = 2 4, which is high), and a rule of thumb to avoid overly truncating the distribution
23	The soil ingestion rate for an adult does not seem reasonable	The EPA default reasonable maximum exposure (RME) soil ingestion rate for adults was used because the workgroup was concerned with the adequacy of the existing database on adult soil ingestion We agree with the reviewer that the use of this high-end value as an input to this influential parameter, will interject a conservative bias into the outcome Now that an RME point estimate calculation is to be included in the report (per another reviewers comments), it would be beneficial to use a distribution for adult soil ingestion for comparative purposes **The final workgroup decision was to use a distribution for the adult soil ingestion rate*
24	Figure A-7 is off the page and useless, and the text on page 32 is continued to some unknown location	This will be corrected in the final report
25	Reviewer proposes a point-by-point comparison of RSALs computed in the Task 3 Report with screening levels computed for similar scenarios in NCRP 129, and suggests that there is good agreement between them	Upon closer examination, it appears the reviewer has not selected the appropriate NCRP scenarios for comparison with the Task 3 scenarios The scenario PV, as described in the key does not admit dwellings, but is instead a scenario for non-residential farm workers, and as such, does not compare with the

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		Rural Resident scenario It appears from the key that the scenario SU (suburban sites with gardens and children) more closely compares with the Rural Resident Likewise, it appears that the NCRP scenario PS (for a sparsely vegetated, and grazing land) more closely compares with the Resident Rancher scenario than the AG (which does not admit children and is a farm rather than a ranch) With the proper match for rural resident the agreement between NCRP and our effort is not as good 32 pCi/g for the SU scenario and 209 for the rural resident The agreement is also not as good in the case of the rancher either 16 pCi/g for PS vs 45 pCi/g for the rancher (It is worth noting that the RAC Rancher scenario, presented in Appendix G, includes an entirely unrealistic value for mass loading, and if the same scenario were modeled using a mass loading distribution similar to what has been used in the Task 3 scenarios, that a value in excess of 100 pCi/g would be computed) If the scenarios are properly matched, and the Rancher scenario is adjusted for realistic mass loading, it becomes obvious that the NCRP 129 approach is much more conservative than that used by the working group, and that the caveat appearing on page 8 of NCRP 129 is well founded
26	The recovery curves following a fire made sense to the reviewer	While the recovery curves are based on a very limited data set, the results are consistent with other results in the literature with regard to the shape of the recovery curve, but seem to indicate a somewhat slower recovery than has been observed in other settings
27	The discussion of the RESRAD Inhalation area factor was not clear to the reviewer	The working group will review the text, and attempt to clarify this relatively complex discussion The area factor is a mathematical representation of the phenomena associated with the influence on dust loading from variable source areas A smaller source area will contribute less airborne dust than a larger source Coupled to this simple observation is the additional simple observation that a source area distant from a receptor (someone breathing the dust) has less influence than a nearby source area An increasing area, while it contributes more, also carries the physical consequence that the additional emission contribution is further from the receptor The two factors eventually reach a balance in which the increase in area is offset by the increased distance, to the extent that the amount of dust inhaled

	Review Comments – Reviewer 2	Response
		by the receptor does not measurably increase with the increase in area – in other words, the inhalation pathway becomes "saturated", not responding any more to changes in the source area
28	In general, the reviewer thought that the values recommended in the child soil ingestion rate distribution are consistent with other analyses he has seen, and that "the ingestion rates have been adequately quantified for the intended purposes" The reviewer expressed some doubts as to whether 1,000 mg/d could really be sustained by a child for any length of time	Same as Comment #22 above
29	Confusing presentation of uncertainty discussion in Section VI Reviewer was unclear as to why draft Task 3 identified possible sources of uncertainty if it wasn't going to be quantified The reviewer indicates that a "2-dimensional analysis must be conducted whereby separation (between variability and uncertainty) is maintained	Section VI will be expanded to include further discussion of how uncertainty relates to the choice of probability distributions for variability, how the sensitivity analysis plays a role in interpreting the importance of the sources of uncertainty, and collectively what the overall uncertainty is in risk and RSAL values based on a semi-quantitative ranking of the confidence in the values (or distributions) selected for input variables Table VI-1 will be revised to reduce ambiguity in the descriptions of variability and uncertainty While we agree that a 2-D MCA can be informative for risk managers, it represents an additional complexity in the analysis that was beyond the scope of this assessment Uncertainties were discussed qualitatively in this assessment **Section 6 is now Section 7*
30	The reviewer thinks that combining data from different studies which are weighted appropriately according to whether they used mass-balance or not would likely not result in a different distribution than that from the Anaconda study Since this distribution is not inconsistent with that from the independent NCRP Report 129, 1999, the reviewer though the analysis done in draft Task 3 was appropriate	We agree
31	Page 6 Reviewer has never heard of the concept of pathways being considered complete	The concept of complete pathways is described in EPA's 1989 Risk Assessment Guidance for Superfund, Part A on page 6-17 A pathway is complete if there is 1) a source or chemical release from the source, 2) an exposure point where contact can occur, and 3) an exposure route by which contact can occur
32	Page 9 Reviewer has problem with the use of	The text will be revised to use conventional jargon

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	the term "conduit" to describe a pathway He recommends using conventional jargon, not to change terms or invent new definitions	
33	Page 9 Reviewer has never heard of the term "active pathways" All pathways should be realistic Use conventional radioecological definitions	The concept of "active pathway" is not intended to represent some physical phenomenon Instead, it is a way of denoting the state of the model in the way it will handle parameters associated with that pathway An active pathway is that segment of the model's code that is used to estimate dose or risk from a certain physical pathway, an inactive pathway is one that is turned off in the model
34	Page 9 Reviewer does not believe that the assumption that the "surrounding areas" of the residential site are uniformly contaminated is realistic, and cites several articles that indicate that Rocky Flats is not uniformly contaminated Reviewer believes that overly conservative bias is interjected into the analysis by oversimplifying the model in order to make calculations easier	The working group has discussed the implications referred to in this comment While it is true that the residential site could be located where the surrounding area is not uniformly contaminated, the scenario examined was a 5 acre plot sited in the most impacted point within a 300 acre area that would have been cleaned to the RSAL level and no more This results, appropriately for the calculations, in a uniformly contaminated surround For any resident other than this one, however, the working group agrees with the reviewer that the results would be overly conservative It further agrees that the scenario may be conservative even for the most impacted resident since it is unlikely that the 300-acre area would be entirely contaminated to the RSAL level
35	Page 18 As part of the water discussion, the Reviewer would like a discussion of how activity of particles can change with size	The working group does not see the utility of the discussion suggested by this reviewer in the context of this document Water is not considered a viable contributor to dose or risk in the scenarios examined by the working group In addition, there is insufficient information available regarding the size distribution of the plutonium attached to the colloidal particles to provide more than academic interest to the discussion
36	Page 19 The equation for the RSAL based on risk provides no units for the parameters The multiplication signs in the risk equation show in the document as left-printing arrows The paragraph above the risk equation uses the wrong terminology First, there is no dose equation Second, the Reviewer believes the word "activity" should have been used instead of "exposure" Similarly the word "exposure" was used instead of "intake" on p 46, 2nd paragraph, last sentence	Units will be added to the risk equation, font corrections will be made, and terminology will be corrected, as necessary The dose equations used by RESRAD are described in the User's Manual for RESRAD 6 0, "Exposure" as we used it refers to external radiation and internal intakes and is consistent with the more general definition of exposure typically used in Superfund risk assessment

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37	Page 20 The uncertainty around EPA cancer slope factors and dose conversion factors should be quantified, since these factors are the most uncertain parameters The reviewer believes that using point estimates for these parameters "falsely expresses a belief in the values used as extremely high and that alternative values are unlikely"	We agree with the reviewer that the toxicity values may be a significant source of both variability and uncertainty in a risk assessment At this time, however, EPA recommends that probabilistic distributions not be developed on a site-specific basis for human toxicity values The qualitative uncertainty surrounding the use of dose conversion factors and cancer slope factors is discussed in Section VI of the report as well as the impact of their use on the results **Section 6 is now Section 7*
38	Page 29 The reviewer did not understand the material presented in Section IV-3 Specifically, the reviewer did not understand what was meant by a "saturated" pathway	See the response to this reviewer's comment #27 for an example of the concept of "saturation" Saturation *(of the modeled dose)* occurs in a calculation of pathway contribution when an additional increase (or decrease) in one of the variables driving the pathway contribution no longer results in a significant increase in the pathway contribution The pathway becomes insensitive to additional increases (or decreases) in that variable
39	Page 31 Reviewer wants qualification of the statement that inhalation rate is linearly related to dose and risk only when the particle size remains constant	This is a very important conceptual comment The statement carries with it the assumption that an increase in breathing rate will not change the particle size <u>distribution</u> of contaminated material being deposited in the lungs It is possible that increased breathing rate will result in a change from nasal breathing to mouth breathing, with the consequent admittance into the oropharynx (region extending from the soft palate to the glottis, essentially the "throat") of larger contaminated particles than would be admitted through the nasal passages These larger particles are not efficiently transmitted through the tracheobroncheal region (windpipe) into the pulmonary region (deep lung), and very few, if any, of the larger particles would be deposited in the lungs Instead the particles would be deposited in the throat and ultimately ingested (swallowed), or expectorated (spit out), depending on the habit of the receptor and possibly the intensity of the dust exposure It is likely that mouth breathing would result in a net increased dose, compared to nasal breathing, but through the digested fraction rather than the inhaled fraction However, the models assume all particles are 1 □m size This assumption consistently overestimates transport into the lungs and GI tract
40	Page 34	See response for comment #3 above

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	Review Comments – Reviewer 2	Response
	Interjection of bias by the working group by refusing to assign distributions for variables with sparse data, and using, instead, point estimates Reviewer believes uncertainty should always be quantified	
41	Page 36 to 41 Quality of presentation Tables IV-3 and IV-4 are needlessly confusing and sloppy Pages that are continued do not have column headings Way these tables are presented in the document is so that one has to read right to left The parameters of each distribution are shown, but the definitions for them, i e , min, max, etc are not	Text and tables will be edited to improve presentation Definitions for parameter of probability distributions will be added
42	Inadequate statement of purpose of the probabilistic analysis, up-front Reviewer wants a quantitative uncertainty analysis Confusing presentation of uncertainty discussion in Section VI	Same as comment #2 above
43	Page 53, first paragraph, last sentence Interjection of bias by working group's refusal to assign distributions for variables with sparse data, and using point estimates instead	We feel that the reviewer misinterpreted the text On page 53 of the report we state "As general practice the RSAL working group tried to present data as accurately and factually as possible without interjecting bias However, when data sets were sparse and highly uncertain, the working group defaulted to a conservative point estimate" We did not say that we were always accurate in our representations We acknowledge that there are times when there is not enough information to accurately represent a variable In those situations, we realize that we may be interjecting bias by defaulting to a conservative value, and we discuss this qualitatively in the uncertainty section (Section VI) The intent of Section VI is to inform the decision makers of the consequences of interjecting bias and uncertainty into the calculation
44	Page 55 and 56 Confusing presentation of uncertainty discussion in Section VI Reviewer wants a quantitative uncertainty analysis Quality of presentation Tables VI-1 through VI-5 read from right to left, with successive pages located to the right	Section VI will be expanded to include further discussion of how uncertainty relates to the choice of probability distributions for variability, how the sensitivity analysis plays a role in interpreting the importance of the sources of uncertainty, and collectively what the overall uncertainty is in risk and RSAL values based on a semi-quantitative ranking of the confidence in the values (or distributions) selected for input variables Table VI-1 will be revised to reduce ambiguity in the descriptions of

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		variability and uncertainty While we agree that a 2-D MCA can be informative for risk managers, it represents an additional complexity in the analysis that was beyond the scope of this assessment Uncertainties were discussed qualitatively in this assessment **Section 6 is now Section 7*

	Review Comments – Reviewer 3	Response
1	Page 8 It seems confusing to me to put volatilization from the soil in the Site Conceptual Model and then in a subsequent paragraph state that volatilization is not considered in this report because that is only an issue with uranium, and not plutonium or americium Will that be addressed differently when uranium is added to the report? This issue arises with all of the Site Conceptual Models	The Conceptual Site Models are designed to include both radionuclides and other contaminants The models will be modified to distinguish between volatilization and radon pathways Radon in-growth from site-contributed uranium is not an issue due to the extremely long time required for in-growth of significant amounts of the radium parent of radon The radon inhalation pathway will be clarified and designated as insignificant on the Conceptual Site Models and the footnote removed
2	Page 18, III-3, 1st paragraph The AME group now believes that americium in the environment at RFETS is due to its being released with plutonium, and not due to in-growth Does this new information have any effect on the results?	The information provided in a public meeting with the AME advisors was not new information to the RSAL working group, nor does it have any influence on the results of the RSAL calculations RSALs have been calculated individually for americium and plutonium, and those results combined through the sum-of-ratios method to provide the example calculation of an RSAL for weapons-grade plutonium In areas where the ratio of plutonium-to-americium differs from the weapons-grade ratio, the sum-of-ratios method still applies to the calculation of an RSALs (The sum-of-ratios method will use site-specific information on americium and plutonium concentrations to derive site-specific RSALs)
3	Page 18, III-3, 3rd paragraph Just a comment that, as per Chris Dayton, the aseptic groundwater wells showed Pu contamination (albeit very low-level) and so the search continues for the source of contamination	The comment is correct, work continues in the AME to more cleanly sample groundwater wells that have shown detectable amounts of plutonium in order to better understand the origin of that contamination Notwithstanding the absence of results from those additional samples, there is no evidence of plutonium or americium-contaminated groundwater plumes at Rocky Flats The site does have plumes contaminated with uranium
4	Page 19 What are the units on the RAGS equation parameters?	Units will be added
5	Page 23, Table IV-2 The value used for the Area of Contamination Zone is outside of the range of sensitivities tested While the model is not very sensitive to this parameter, is it anticipated that the effect of this parameter on the final number will not differ at higher values from the effect at lower values?	The reviewer's anticipated answer is correct The areas being modeled for Rocky Flats are large enough that all pathway contributions have reached their limiting values
6	Table IV-2 Were parameter values labeled as "distributions" in the "Value Used" column	The extremes of many of the distributions may be found to lie outside the sensitivity ranges tested, but the results of the sensitivity analysis are still valid

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	within the sensitivity ranges tested? If not, I ask the same question I asked in 5	when the majority of the distribution lies inside the range It is important to remember the purpose of the sensitivity tests and the basis of the mathematical formulations that are being tested The purpose of the sensitivity tests is to detect any nonlinear behavior that could portent a behavior in the model that would not be adequately represented in the choice of an input parameter, or interacting parameters The mathematical formulations and their interactions, while understood, could yield overlooked consequences if not tested over a range of input variables that allows assessment of the model's response characteristics The tests for sensitive parameters will reveal one or more of several behaviors - little or no sensitivity to changes in the input variable, a change in output that is more-or-less directly proportional to the change in input, and resulting in relatively large changes in output, or a change that exhibits strong non-linear response to changes in input The latter will be identified as extremely sensitive responses, the more greatly influenced proportional case will typically be sensitive or moderately sensitive, and the small proportional response or non-response will be insensitive The conclusion that the sensitivity analyses are valid for the distributions comes from the realization that these parameter responses are really well characterized in the model and have relatively simple interactions with other parameters The working group will examine the discussion to ensure better clarity
7	Table IV-2 The value used for the external gamma-shielding factor was outside of the range of sensitivities tested The model is moderately sensitive to this parameter I ask the same question asked in 5	This parameter is moderately sensitive and was hence important to examine in detail Since the gamma-shielding factor is a physical parameter, its characteristics can be readily predicted and adequately represented as a point value
8	Page 45 How and why was the 96th percentile mass loading value used for calculations? Does this percentile take the fall fires into account, since they are above the 96th percentile?	The deterministic (point-estimate) RSAL calculation was performed using a mass loading value very close to the 95th percentile The probabilistic RSAL calculations were performed using the entire distribution The risk-based RSAL results exhibited in the Executive Summary and any future RSAL recommendation on a final RSAL selection will be based on the probabilistic calculations, and will by default be based on a distribution of mass loading that takes the fall fires into account

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	Review Comments – Reviewer 3	Response
		**In the final deterministic RSAL calculations a mass loading value equal to the 95th percentile concentration was used*
9	Page 49 Another suggestion Make it clearer within the text and title for the SOR table that the SOR table shows only an example of RSALs, based on a given location and that if the Pu Am ratio changes, the RSALs will also change	The titles of the SOR tables will be changed to include the word "example " The last sentence of Section V will be modified to read, "The approach for calculating sum-of-ratios is discussed in Section V-1 below, and example sum-of-ratio values are shown in Tables V-1 and V-2 " The last paragraph of Section V-1 will be modified as follows "Whenever a sum-of-ratios-adjusted action level is presented, it is important that the Am Pu activity ratio used be specified The Am Pu activity ratio used to calculate the examples in Tables V-1 and V-2 is 0 17, which is the inverse of the 5 815 Pu Am activity ratio reported in the 903 Pad characterization report (DOE, 2000) " **Section 5 1 states that an activity ratio of 0 182 was used to calculate example sum of ratio values*
10	Page 50, V-2 What is the time frame for RSAL exposures? Are they to be protective over a 25-yr average, or for an annual average for 25 years?	The dose-based calculations are based on one year of maximum dose (which was year one) The time frame for the risk-based calculations was treated in a probabilistic manner (Rural Resident and Refuge Worker), each realization of the probabilistic analysis represents a hypothetical lifetime exposure The parameter of exposure duration was input as follows • Rural resident 1 to 87 yrs with mean of 12 6 and standard deviation of 16 2 years, • Wildlife refuge worker Distribution with mean value of 7 2 years with a standard deviation of 7 years, The analysis for Open Space User and Office Worker are point estimates of lifetime risk where the exposure durations are • Open Space User 30 years • Office Worker 25 years
11	Page 51, last paragraph "Because RSAL calculations, for the most part, are the inverse of risk calculations, the reasonable maximum exposed range for RSALs corresponds to the 1st through 10th percentiles, with the 5th percentile as the recommended starting point " Are RSAL calculations the inverse of risk calculations? Is the intention to say that the 99th % RME risk corresponds to the 1st % RSAL?	The reviewer has the correct concept of the relationship between the risk distribution and the RSAL distribution The footnote in Table V-3 indicates that the 10th to 1st percentile for RSAL range corresponds to the 90th to 99th percentile of the risk distribution, which is also referred to as the RME range

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	Review Comments – Reviewer 3	Response
12	12) Appendix B, page 4 What is the Area Correction Factor used in the RAGS equations for External Exposure? Is this the same parameter used in RESRAD? If so, I thought the RAGS equations didn't use that dilution factor	The reviewer is correct, the RAGS equations do not use the Area Correction Factor (ACF) However, the newly revised equations for external exposure in EPA's "Soil Screening Guidance for Radionuclides User's Guide" (2000) ("SSG for Rads")(referenced in the text) were used instead The ACF in the "SSG for Rads" corrects for a reduced gamma exposure in the case of small areas of contamination (hot spots) It would not have entered into the calculations for plutonium or americium in a significant way since the areas of contamination modeled (5 acres) are much larger than the hot spot areas where external exposure reaches its limiting value (a few hundred m^2) However, the ACF is significant in the case of the uranium calculations, since uranium contamination at Rocky Flats is present as small hot spots The ACF in "SSG for Rads" is found by looking up the area and photon energy in a pre-calculated table It appears that RESRAD, which uses a point kernel mathematical formula and calculates the ACF based on area and photon energy gives identical results to "SSG for Rads" for identical inputs, and the working group has assurance from the ORIA staff who authored the Soil Screening Guidance that the mathematical formulas in "SSG for Rads" and RESRAD are the same We therefore propose to use the RESRAD formula to calculate ACFs for use with the Standard Risk equations for uranium isotopes and areas not appearing in the "SSG for Rads" table

	Review Comments – Reviewer 4	Response
1	Overall, the spreadsheet is crafted nicely and easy to follow There are a few issues of style that I will discuss later	No response needed
2	The single largest concern is that of security None of the cells in the spreadsheet are locked It is very easy to modify cells unintentionally	Only a few members of the workgroup used the working spreadsheets, and calculations were crosschecked Spreadsheets were distributed for others to use to understand and test various assumptions, but their results were not incorporated into the RSAL calculations However, we agree that once the risk assessment is finalized, it would be necessary to develop a duplicate copy of all spreadsheets that has security features
3	In my examination of the four spreadsheets, I uncovered only one spreadsheet whose equations were not consistent with Appendix B The risk equation for inhalation for an Open Space User read in Appendix B as $Risk_{inhalation} = PRG * IR_{a\_age} * ED * EF * ET * ML * CF_I * SF_{inh}$ where * indicates multiplication In the actual spreadsheet, this computation is given as $Risk_{inhalation} = PRG * IR_{a\_age} * ED * EF * ET * ML * CF_I * [ET_0 + ET_i*DF_i]* SF_{inh}$ Where ET_0 = Exposure time fraction, outdoors, ET_i = Exposure time fraction, indoors, and DF_i = Dilution factor, indoor inhalation This latter formula is analogous to the one used for the residential scenario	The equation used in the spreadsheet is correct, since a variable for exposure time is needed in the Open Space User scenario The equation in the text will be updated
4	There is also an error in labeling The acronyms for "Inhalation rate, child" and "Inhalation rate, adult" in cells C14 and C15 are reversed Both Am-241 and Pu-239 have their inhalation risk computed using this latter formula	The labels on the spreadsheet will be modified as suggested by the reviewer
5	One further comment is on style It would preferable to have the adult data consistently placed before the child data in this spreadsheet In light of this remark, interchanging rows 21	This apparent minor modification would require substantial effort to change all equations and re-perform a QA/QC check We believe the minor change is not warranted

	Review Comments – Reviewer 4	Response
	and 22 would be helpful However, all of the formulas are correct and consistent with the current arrangement	
6	In the process of examining the Open Space scenario, there appears to be a mistake in the variable definitions as follows IR_{a_child} = inhalation rate for children, and IR_{a_adult} = inhalation rate for adults, should be ingestion rates If not there is a further error in the spreadsheets regarding these variables	The labels on the spreadsheet will be modified as suggested by the reviewer
7	All of the slope factors for toxicity levels new and old inputs The spreadsheets consistently reference only the new data It is not clear to me why the other "old" data is entered at all but the references are consistent throughout all of the spreadsheets	The database of slope factors has evolved during the course of the risk assessment The spreadsheet simply documents the different values that have been considered
8	The residential scenario spreadsheet • Is ED the same as $ED_{\_age}$ in cell C24? It appears that it is • Why is cell E16 rounded from 8 71 to 8 7? • Why is 210/1445 in cell E20 rounded to 15? • Why is 1235/1445 in cell E21 rounded to 85? The equation for food risk in cells E60, E61, E69, and E70 are cumbersomely implemented However, they are correct	a) Yes, ED and ED_age are the same The subscript denotes variables for which an age-group weighted value is presented b) Comment no longer relevant as point estimate has been changed to 8 3 based on data provided by Layton c) and d) The values in cells E20 and E21 should sum to 1 0 to correspond with 1440 minutes per day d) No change
9	The Wildlife Refuge Scenario spreadsheet The origin of the computation (J14+(K14-J14)*F14) for the probabilistic risk in cells C41 and C42 are unclear It appears as though the inhalation rate is computed using this formula	This computation is used to scale the beta distribution to reflect the inhalation rate data The beta distribution is theoretically defined across the interval 0 to 1 A discussion of the scaling approach is given in Appendix A (pp 47-49)
10	The Office Worker scenario spreadsheet The point estimate and probabilistic data are identical Why have the two separate schemes if only one is going to be used In cells C6 through F6 and C7 through F7, the values are toggled between point estimates probabilistic using a value input in cell B52 If B52 = 1, the values recorded in theses cells will be based on point estimates Otherwise they will be based	Because of the time and resources required to develop distributions for multiple scenarios with hundreds of parameters, a decision was made by the workgroup to conduct probabilistic assessments only for the scenarios that would add the most value to the remedial decisions at Rocky Flats These were the Rural Resident and Wildlife Refuge Worker The Open Space User and Office Worker scenarios were done using a point estimate approach Because we

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	on probabilistic estimates In this spreadsheet there are no probabilistic estimates being used However the value in B52 is set to 2, indicating that probabilistic estimates are requested All in all this approach seems to be unnecessary	wanted to maintain consistency across the spreadsheets, the spreadsheets for Open Space User and Office Worker are set up to take distributions for entries, but only point estimates were entered and used We agree that this may appear redundant, but we felt that the consistent approach would make review much easier for the layperson

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	Review Comments – Reviewer 5	Response
1	Overall, the report is well-organized, surprisingly readable given the number of contributors to it, and contains key information necessary to understand the science supporting the risk assessment	No response needed
2	While not necessary for communication between professionals, page numbers within specific citations would help the layperson find information contained in some of the bigger documents I had trouble, for instance, finding a statistic of interest in the Exposure Factors Handbook As this reference is really a compendium of studies, it would be helpful to know exactly which study the statistic came from and on what page number it could be found	The working group will add to the citations as appropriate
3	Inconsistencies between the scenario description and the scenario parameters chosen can be extremely misleading For instance, the refuge worker is not someone "assumed to work eight hours per day for five days per week and for 50 weeks per year " (p 7)	The working group will make appropriate revisions to the report
4	Tables VI-1, 2, 3, 4 should clearly distinguish between those areas where the working group has followed standard methods used by risk assessors to account for uncertainty (e g placement of the receptor on the contaminated area is a standard assumption in risk assessment) and where they have added an extra measure of conservatism (e g setting depth of contamination equal to depth of roots) This would better enable to risk managers to assess whether the risk estimates strike an appropriate balance between realism and conservatism	Section VI will be expanded to include further discussion of how uncertainty relates to the choice of probability distributions for variability, how the sensitivity analysis plays a role in interpreting the importance of the sources of uncertainty, and collectively what the overall uncertainty is in risk, dose, and RSAL values based on a semi-quantitative ranking of the confidence in the values (or distributions) selected for input variables The tables in Section VI will be revised to more clearly distinguish between those parameters and assumptions where the working group followed standard methods used by risk assessors and where we have added an extra measure of conservatism **Section 6 is now Section 7*
5	Although the conclusion of Section VI makes a weak attempt to show that the risk assessment strikes a reasonable balance ["This conservatism is balanced *somewhat* by use of average ingestion rates By doing this, it was *hoped* that a balance could be struck " (p 84, emphases mine)], the tables themselves (Tables VI-1, 2, 3, 4) do not seem balanced, and run the hazard of giving the risk managers and DOE headquarters the impression that the	The conclusions in Section VI will be reviewed and rewritten, as necessary, in order to provide a clearer explanation of the sources of conservatism or realism in the RSAL calculations **Section 6 is now Section 7*

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	Review Comments – Reviewer 5	Response
	risk assessment is unrealistically conservative An example of this, I believe, is the exposure frequency for the rural resident (p 70) The distribution is based on data from the Exposure Factors handbook that show the average person spends 64% of their time at home This choice, which the report calls "relatively conservative," is arguably quite realistic	
6	As stated in the report, risk assessment guidance supports giving point estimates along with the probabilistic results This could easily have been done, and perhaps should have been done, for the benefit of the risk managers, who need to know if the probabilistic calculations differ significantly from the point estimate approach, and if so, why	We agree with the reviewer that point estimates should be provided along with the probabilistic estimates for perspective These will be added to the report When comparing the two, the point estimate value (which represents the RME individual) should be compared to the probabilistic RME range (e g , the values between the 90^{th} to 99^{th} percentiles) If the point estimate is markedly different from the RME risk range, the reader should examine the inputs to the risk equations and seek to understand why they are different
7	I believe the report should also do a better job of explaining the strengths and weaknesses of the risk assessment process used in the Task 3 Report For instance, the risk managers should be aware that, while EPA guidance does not recommend modeling cancer slope factors as probability distributions, the point estimates used are central tendency estimates The study "Assessing the Risks of Exposure to Plutonium from Inhalation and Ingestion" (Grogan, et al) speaks to the possibility that the cancer risk of exposures to plutonium may vary by orders of magnitude Consequently, had this variability been reflected in the inputs for the cancer slope factors, there might have been a substantial effect on the RSAL	See response to comment #37 above from Peer Reviewer #2
8	P 7, para 3 Refuge worker scenario description is misleading "Refuge worker is assumed to spend 8 hr/day, 5 days/week, 50 weeks/year" on site This implies use of a point estimate, when in fact the exposure frequency parameter is being treated probabilistically, with an average of 225 days per year and a range of 200 to 250 days per year	We agree – the description is relevant only to the point estimate assessment The text will be clarified
9	P 9, para 4 Rural Resident scenario description is technically correct when it says resident spends "up to 350 days per year on site " More informative, however, would be to give the range (175 – 350) and the average	We agree The text will be clarified

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	value of 234 days per year	
10	P 43, last para Change the word "RESRAD" to "RSAL "	This will be changed
11	P 53, 1st para Report speaks to importance of assessing the strengths and weaknesses of information used in the modeling (e g parameter inputs), then says "These strengths and weaknesses should be communicated to the risk decision makers for them to make health-protective remedial decisions " Now that the working group is no longer in a rush to finish the report, they should go through the report methodically to make sure they have achieved this goal in a balanced, accurate fashion	Section VI will be expanded to include further discussion of how uncertainty relates to the choice of probability distributions for variability, how the sensitivity analysis plays a role in interpreting the importance of the sources of uncertainty, and collectively what the overall uncertainty is in risk and RSAL values based on a semi-quantitative ranking of the confidence in the values (or distributions) selected for input variables Table VI-1 through Table VI-5 will be revised to reduce ambiguity in the descriptions of variability and uncertainty **Section 6 is now Section 7*
12	P 55, para 5 Report states "no attempt was made in this assessment to quantify uncertainty " Is this really true? Probability distributions were chosen for some scenario parameters, such as exposure frequency and duration Page 56 states "There is scenario uncertainty intrinsic in all of these choices "	The reviewer's comment reflects a common practice of loosely using the terms variability and uncertainty whenever a probability distribution is used For probabilistic risk assessments, a more rigorous distinction is needed because the concepts are different (see descriptions in Section VI), and different approaches can be used to quantify each One of the more confusing points is that our choice of distributions for variability are themselves a source of uncertainty The text will be expanded to make this clear The intent of the statement that no attempt was made to quantify uncertainty is to clearly tell the reader that the Monte Carlo analysis was restricted to exploring variability, not uncertainty **Section 6 is now Section 7*
13	P 57, para 1 "In other cases, such as exposure duration for the rural resident, quite a lot of confidence can be placed in the distribution chosen " This distribution came from a recommendation made by EPA in the 1997 Exposure Factors Handbook EPA assigned a confidence rating of high, medium or low to the various parameters recommended Exposure duration received a medium confidence rating	We agree, the text will be modified to read, "In other cases, such as exposure duration for the rural resident, greater confidence can be placed "
14	Sect VI, p57-83 A potentially important piece of information that appears to be missing from this section is whether the modeling choices made by the working group adhere to standard practice in risk assessment This would enable the RFCA principals to ascertain where in the	The general approach was to follow existing Agency guidance when possible For many of the exposure variables, the Exposure Factors Handbook is a useful resource, but the workgroup did not restrict its evaluation of available information to the guidance For example, more recent analyses were considered

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	Review Comments – Reviewer 5	Response
	risk assessment the WG has added an extra measure of conservatism, and where they have simply followed accepted methods	in the development of inputs for inhalation rate (e g , Allan and Richardson, 1998) and childhood soil ingestion rate (Stanek and Calabrese, 2000) A distinction should be made between the approaches used for developing point estimates and probability distributions The following guidelines were followed For variables described by point estimates in both the point estimate and probabilistic approaches, the same value was used Preference for point estimates was given to EPA's recommendations for reasonable maximum exposure (RME) If a probability distribution was used for the probabilistic approach, the corresponding point estimate was evaluated for consistency with the probability distribution (e g , central tendency or 95th percentile)
15	P 58, 59 Report fails to point out large uncertainties inherent in cancer slope factors Slope factors themselves are central tendency estimates that may either over- or under-estimate risks	See response to comment #37 above from Peer Reviewer #2 **Section 6 is now Section 7*
16	P 59, last entry Report fails to point out that for inhalation pathway, RESRAD also assumes dilution of contaminated dust from upwind fetch The model assumption of wind constantly blowing means model is taking credit for constant dilution as well Wind tunnel studies suggest that, while this assumption may be appropriate for point source emissions, it is an oversimplification in the case of fugitive dust emissions, such as occur with dispersed surface soil contamination	This is an important comment to explore The wind tunnel results are properly interpreted to indicate the contribution from wind events will be highly dependent on the direction of wind during the relatively short-lived events The direction of the wind during the next high wind event will not necessarily be in the same direction and will not necessarily contribute to the same receptor direction The consequence of this is that the estimated annual mass loading attributions in the post-fire years are overstated Regarding the effect of dilution, fugitive emissions are the source contributing to these RSAL calculations, and depend on the wind for both emission strength and dilution The use of the total emission rate to be overestimated under lesser wind conditions than the extreme used to calculate the erosion potential The overestimated emissions would then be diluted in a typical dispersion model RESRAD and the Standard Risk equations do not perform dispersion modeling, but rely instead on simpler area weighting to estimate the contribution of a limited source area to the estimated mass loading

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	Review Comments – Reviewer 5	Response
		Since the mass loading following a wildfire was estimated using a simple multiplication factor developed from the wind tunnel date, the implicit assumption is that the emission rate will be increased by the same amount at all wind speeds Dilution effects are also assumed the same in both normal and burned areas
17	P 60, 4th entry INCORRECT Fire is <u>NOT</u> assumed to occur every year on contaminated area, but only 10% of the time Also, statement on burn frequency is confusing Burn frequency of once every 10 years, or 10% is assumed While this may be a conservative assumption, the probability of a wildfire on contaminated grassland at some point in the future is 100% Conceiving fire as a prescribed burning regimen was done mainly for ease of computation, and the difficulty of estimating a burn frequency due to wildfire, not simply to add a margin of conservatism	The reviewer is correct, this entry needs to be corrected in the table The reviewer is also correct as to the origin of the distribution, it is based on a predictable frequency The consequence of a more conservative result is a secondary outcome
18	P 60, last entry Not necessarily I know a doctoral candidate at Colorado State University whose research has focused on Rocky Flats, and who asserts that the maximum Am dose occurs at Year 2038	It would not be possible to know the exact year for the maximum effect of americium in-growth in the residual contamination at Rocky Flats The americium present in the environment is mostly from contamination deposited around the 903 Pad, resulting from spills of weapons-grade plutonium cuttings generated in the '50's and early '60's The actual age of the contamination is thus subject to an uncertainty of +/- ten years or so It is important to recognize however that the in-growth of americium has proceeded for at least 40 years from that time, resulting in an in-growth that is more than 90 percent of its maximum value To more completely address this issue, the working group has decided to use an equilibrium Am/Pu ratio (18 2%) occurring at year 86 for its revision of the general sum-of-ratios calculation Other areas on the site have americium in the soil that appears to be the result of direct contamination from americium source material In these areas, the additional in-growth of americium from aged plutonium will be inconsequential Please be aware that the sum-of-ratios calculations appearing in the Task 3 Report represent general conditions When RSALs are applied, the sum-of-ratios will be based on the measured Am/Pu activities, which vary across the site The text will be revised

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	Review Comments – Reviewer 5	Response
19	P 62, 1st entry For the rural resident, whose 5 acre ranchette is much smaller than the contaminated area, the assumption that he/she spends the entire time on the contaminated area is realistic, not "very conservative" as characterized by the working group The same assumption for the refuge worker, whose geographic range would likely extend over the entire 6500 acres, is very conservative	The text will be revised Also, see answer to Reviewer's 7 comment #3
20	P 62, 3rd entry For the adult soil ingestion parameter, on which almost no data exists, it is speculative to say the 100 mg/day point estimate is "relatively conservative " Better to call it a highly uncertain parameter	The decision to use a point estimate for the adult soil ingestion rate variable has been reconsidered, a uniform distribution will be used In addition, for each exposure variable discussed in Appendix A, an additional statement will be made about the level of confidence in the point estimate or distribution This statement will follow a semi-quantitative ranking (i e , low, medium, high) based on professional judgment
21	P 70, 2nd entry When exposure time is viewed in conjunction with exposure frequency and outdoor time fraction, it is clear that the receptor being modeled is not homebound or an invalid On days when the resident is home, he/she is indeed home 24 hours However, since the distribution being used for exposure frequency has a mean of 234 days per year, the average receptor actually spends a great deal of time (a third of the year) away from home	The reviewer's observations are correct While 234 days/year is the central tendency of the distribution, the high end is 350 days per year (only 2 week away from home) These data are based on relatively large (n > 1,000) surveys of time use patterns among U S adults
22	P 70 The 75th percentile values used for indoor/outdoor time fraction seem are neither average values, nor upper end values, but something in between Is this what is meant by the term, "relatively conservative?"	Yes This variable presented a challenge since the total of indoor and outdoor time fractions need to sum to 1 0 The use of the 75th percentiles was a professional judgment
23	P 70, last entry The exposure frequency distribution is based on one statistic, the percentage of time the average American spends at home (64%) Multiplying by 365 days per year gives 234 days per year, which becomes the mean of the triangular distribution developed by the working group The upper and lower truncation limits were chosen on the basis of professional judgment, with 350 days considered to be the maximum and the minimum arbitrarily chosen as half that Use of a triangular distribution implies the parameter is poorly characterized Is this the case for exposure frequency, or is better data available from which to develop a more accurate distribution? If there is better data,	The reviewer's assessment of the exposure frequency distribution is correct The 234 days/year central tendency is the U S EPA default value, based on national survey data The use of a triangular distribution reflects limitations in the available information – in this case, the original database was not obtained The workgroup will pursue the availability of the database in order to develop a more refined distribution, if a sensitivity analysis suggests that use of alternate distribution types will have a substantial affect on the risk and RSAL estimates

	Review Comments – Reviewer 5	Response
	why didn't the working group use it?	
24	P 72, 1st entry Choice based on standard practice in risk assessment, not the possibility that contamination will be forgotten While it does likely result in over-estimate of risk, report should emphasize that to do otherwise the working group would have been deviating from the professional norm	The choice to locate the wildlife refuge worker on the 300 most contaminated acres on-site is not the professional norm in CERCLA risk assessments Rather, it is the limiting, most conservative possibility, necessary when calculating RSALs Text will be revised for clarity Also, see answer to Reviewer 7's' comment #3
25	P 73, 1st entry Report should emphasize that the point estimate of 100 mg/day is for agricultural workers, not just an average sedentary adult	EPA's standard default RME soil and dust ingestion rate for adult residents is 100 mg/d This value is thought to represent the upper-bound value for soil and dust ingestion, and is based on a limited study (n =6) by Calabrese, et al , 1989, 1990, as referenced in the report This soil ingestion rate is recommended for use as an RME value for both residential and agricultural adults (EPA, 1991, referenced in the report)
26	Appendix A P 31, bottom "For this analysis, the ultimate goal is to use quantitative information on variability and uncertainty in exposure to help inform the risk management decision at Rocky Flats " Contradicts page 55, paragraph 5	The sentence will be revised to delete the word "quantitative" to improve the accuracy of the sentence
27	Appendix A P 47, last para Replace "simply" with "simplify"	Agreed
28	Appendix A P 54, 3rd para "The following probability distribution is recommended for use in risk equations that are based on EPA RAGS guidance " Misleading The guidance recommends the equations, not the distribution The working group chose the distribution based on information from a survey at Rocky Mountain Arsenal	Agreed The sentence will be revised for clarity
29	Appendix A P 56, 2nd entry This receptor's residency period on site is divided between childhood and adulthood, hence, the exposure duration parameter involves an additional layer of complexity that is not transparent in the report If the exposure duration were a point value of 30 years, the parameter would be partitioned as 6 years of childhood followed by 24 years of	The reviewer is correct in his interpretation of the complexity in the approach The Appendix will be revised to include this discussion

	Review Comments – Reviewer 5	Response
	adulthood However, since this parameter is modeled as a distribution, it is not clear from the report alone how the breakdown between child and adult exposures is being handled (Examination of the risk spreadsheet reveals that, for each Monte Carlo realization, the first six years of exposure is attributed to the child – which the working group claims is standard practice in risk assessment)	
30	Appendix A P 61, 2nd para Once again, report implies this exposure frequency distribution for the rural resident is recommended by guidance, when in fact the working group chose it based on data published in the EPA Exposure Factors Handbook	The particular section referenced by the reviewer pertains to the Wildlife Refuge Worker, not the Rural Resident Nevertheless, the sentence will be revised for clarity

	Review Comments – Reviewer 6	Response
1	Professional judgment is used as justification for many of the parameter choices in the report However, the phrase "professional judgment" by itself is not particularly informative To the degree possible, the working group should fully explain the rationale used to arrive at parameter selection	Risk assessment is often based on professional judgment Quantitative scientific data are used when available, but often there is a high level of uncertainty in these data Interpretation and approach has to rely on professional judgment "Professional judgment" should be taken to imply the use of scientifically gathered data, concurrent with the application of the risk assessor's experience in using such data within the professional guidelines established for performing risk assessments
2	Incomplete citations make it difficult to independently verify some of the conclusions reached by the working group	The working group will make appropriate changes
3	The report doesn't do justice to the rigorous scientific debates that took place within the working group In some cases, the rationale given in the report does not fully reflect the logical argument behind the parameter selection A prime example of this is the indoor dust filtration factor, where the report fails to explain why a value at odds with EPA guidance was used	It is difficult in a report of this length and complexity to provide detailed discussions of all the factors considered when selecting input parameters Although the working group used guidance and precedent whenever available, it also exercised the option to improve on existing guidance to be consistent with site-specific or scenario-specific conditions As the reviewer mentions, an example of this is the selection of values for the indoor dust filtration factor The Group opted to use the default value of 0 4 (high protection), for the office worker, based upon the fact that windows would be closed year round, but modified to 0 7 for the resident based upon the assumption that the windows would be open for about half of the year Citations are available from the literature to suggest the value could be as low as 0 3 in a closed home
4	The report should explain parameter selection criteria and the process of how parameters were chosen	Section IV-4 provides a general description of the process for development of probability distributions, including a flow chart depicting the conceptual approach Appendix A provides detailed information for each variable including the data sets available, the strengths and weaknesses of each study, the data sets selected and how the data was fitted to develop the distribution used in this assessment
5	Highly technical language in some sections of the report creates a barrier to understanding for members of the general public who may not have a scientific background	The agencies recognize this problem Significant effort has been made to provide a document understandable to the layman, but the sound development of exposure pathways requires the use of sophisticated scientific tools in many cases In some of these cases, it was not possible to reduce the science to lay terms without loss of the necessary rigor in the analysis The authors attempted to summarize such passages in simpler terms, when it appeared necessary Nonetheless, prior to issuing the draft for

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	Review Comments – Reviewer 6	Response
		public comment, the authors will attempt to identify unfamiliar terms, and replace them with language more accessible to the general public
6	The report should make better use of diagramming and tables Charts and tables should stand alone and make the point so that key information could be gleaned even without reading the entire text of the document	The figures and charts are used for the purpose of illustrating discussions contained in the text They will not be modified to stand-alone
7	Tables VI-1, VI-2, VI-3 and Vi-4, the main part of the section on uncertainty, could be improved through reorganization A grouping according to source uncertainty would be helpful	*The tables in Section VI will be revised for clarity* **Section 6 is now Section 7 These tables no longer exist*
8	At the RFCAB modeling workshop, one of the presenters referred to a soil ingestion study just completed in the state of Washington by a researcher named Davis Did the working group follow up to see whether any data from that study might be useful to the RSAL calculation in estimating this important parameter?	We followed up with Dr Scott Davis on his soil ingestion study in children with pica Because of lack of funding the study was never completed or published We also followed up with Dr Scott Bartell, whom a RFCAB member asked about at a meeting As a graduate student at the University of Washington, he presented an abstract on back calculating soil ingestion rates from blood lead levels in children He estimated a mean childhood soil ingestion rate of 10 mg/day and a 95th percentile of 93 mg/day when the negative mean estimates were included If the negative estimates were excluded, the mean was 42 mg/day and the 95th percentile was 115 mg/day This is consistent with the data from the Anaconda soil ingestion study that was used as the basis of the distribution for childhood soil ingestion
9	The RSAL calculations for the Rural Resident and Open Space User scenarios do not take into account extreme soil ingestion behavior that has been observed in a small (but not negligible) percentage of children If the goal of risk assessment is a realistic estimate of exposure, is it permissible to ignore this real phenomenon?	See response to Peer Reviewer #1, question #3(b
10	The risk equations assume the office worker and open space user both ingest the majority of their daily soil intake while onsite Is this assumption scientifically defensible?	The assumption that the office worker and open space user ingest most of their daily soil intake while on site is probably overly conservative Based on reviewers' comments and further review of the data, the working group will use an adult soil ingestion distribution in the final calculations This distribution will reflect the range of soil ingestion an individual might experience The related uncertainty will be discussed in Section VI
11	Is it appropriate to use soil screening equations, which are simplistic and overly	We feel that the use of the soil screening equations is defensible given the extensive peer review that they

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	conservative and don't take into account ingrowth and decay of radionuclides, to derive an RSAL?	have undergone both within the EPA and within the scientific community The equations do not take radioactive ingrowth or decay into consideration, which tends to make them somewhat conservative, since the initial conditions were selected so that maximum exposure occurs at time zero and decreases with time To assure this, the working group has decided to use the equilibrium Am/Pu ratio (18 2%) which occurs at year 86, in its revised sum-of-ratio calculations This measure completely compensates for the limitation regarding ingrowth in the soil screening equations This bias will be discussed qualitatively in the uncertainty section of Section VI Text will be revised Also see the response to Reviewer 5's comment #18 **Section 6 is now Section 7*
12	The exposure frequency distribution (number of days per year spent on site) for the rural resident is a triangular distribution based mainly on professional judgment It has been said within the working group and elsewhere that use of a triangular distribution implies the parameter is not well characterized Indeed, the only actual data point in the distribution developed by the working group is 234 days per year, taken from a survey of the amount of time the average American spends at home each year Is more information available on this parameter? If so, how does the 95th percentile of the working group's distribution (318 days per year) correspond with actual survey data?	The reviewer's assessment of the exposure frequency distribution is correct The 234 days/year central tendency is the U S EPA default value, based on national survey data The use of a triangular distribution reflects limitations in the available information – in this case, the original database was not obtained The workgroup will pursue the availability of the database in order to develop a more refined distribution, if a sensitivity analysis suggests that use of alternate distribution types will have a substantial affect on the risk and RSAL estimates

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1	In general, this is a good report, clearly written with a thorough and thoughtful process The authors have done a very good job This analysis is one of the most comprehensive and complete ever sent to headquarters	None needed
2	There is much discussion throughout the document about the CERCLA risk range, specifically, how the risk range goes from 10^{-4} to 10^{-6} However, EPA officials have repeatedly stated that the risk range extends to 3 x 10^{-4} In addition, OSWER No 9200 4-18 states, "Guidance that provides for cleanups outside the risk range (in general, cleanup levels exceeding 15 millirem per year which equates to approximately 3 x 10^{-4} increased lifetime risk) is similarly not protective under CERCLA and generally should not be used to establish cleanup levels " Consequently, for this set of risk calculations, it appears that the upper value for the risk range should be 3 x 10^{-4} rather than 1 x 10^{-4} The calculations in this report, as summarized in the table in the Executive Summary on page 1, clearly demonstrate that an annual 25 millirem cleanup level can be within the CERCLA risk range when the risk range is extended (per EPA policy) to 3 x 10^{-4} The risk range can be extended to 3 x 10^{-4} by multiplying the entries at the risk level of 10^{-4} by 3 and comparing the product to the 25-mrem annual dose column For the cases in which there were probabilistic calculations, the 25 millirem per year entry is within the CERCLA risk range For the deterministic calculations, the 25 millirem is not within the CERCLA risk range, however, the 25 millirem limit is subject to ALARA There are two points to this comment First, if the goal of the analysis is to show the range of cleanup alternatives that can be considered, the risk range calculations should be extended to 3 x 10^{-4} This will provide a more comprehensive range under which CERCLA modifying factors can be considered or in the cases of AEA-based standards, define the limit for the ALARA process to consider Second, the document will better show that the CERCLA process using its risk-range constraints and modifying factors results in cleanup options essentially equivalent	The agencies are aware that EPA policy considers values close to 1 x 10^{-4}, such as 3 x 10^{-4} as essentially equal to 1 x 10^{4} However, the policy document in question should not be interpreted to mean that 3 x 10^{-4} is the new, de facto cleanup level for radiologically contaminated sites The National Contingency Plan, the implementing guidance for the Superfund Law, states that remedial action is generally warranted when risk levels exceed 10^{-4}, and when action is warranted, cleanup to 1 x 10^{-6} should be the point of departure in the planning of the cleanup Also, the time spent on site is input as a distribution of values to account for individuals who work offsite as well as stay-at-home fathers/mothers and shut-ins

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	to the AEA-based 25 mrem/year plus ALARA process (*i e* , the process being implemented at Rocky Flats will satisfy all applicable or relevant requirements) The document clearly shows to the perceptive reader that the two processes are very compatible and it would be valuable to make that clearer for those that might not notice	
3	The Wildlife Worker scenario is overly conservative Only 300-400 acres of Rocky Flats has significant levels of residual radioactivity Given the site area of thousands of acres, it is incorrect to assume that a wildlife refuge worker was employed full-time on a small portion of a much larger parcel It is recommended that a more realistic assessment of outdoor occupancy be provided Clearly, given the ratio of lands that contain residual radioactivity to those that do not, it is very conservative to assume all of the workers outdoor time is spent in the areas containing residual radioactivity If it is not possible to get a better estimate of remote to office-based activities for the workers, the conservative assumption should be clearly stated in the Wildlife Refuge Worker section (III-1) a)	We believe the assumption that the wildlife refuge worker would spend all of their work time on the most contaminated 300-400 acres is conservative, but plausible, given CDPHE's estimate of an appropriate size exposure unit for this receptor Using the data on specific tasks done by wildlife refuge workers from the survey performed as part of the risk assessments for the Rocky Mountain Arsenal, the time-weighted average size exposure unit calculated for either "all wildlife refuge workers combined" or for "only those who spent at least 50% of their time on-site outside" is 450-460 acres In addition, a significant proportion of the wildlife refuge workers in that survey reported spending no time/year in tasks that would typically be done on large areas (500-6000 acres) If only this latter group of workers is evaluated, the time-weighted average exposure unit size is approximately 130 acres Therefore, evaluating exposure to a wildlife refuge worker on an area the size of that which contains the highest concentrations of plutonium and americium on-site (down to the 10 pCi/g contour east of the 903 Pad) does not seem unreasonably conservative Rather, for the purposes of calculating a range of plausible RSALs, it could be considered the limiting condition for an average wildlife refuge worker
4	It would also be useful, for clarity, in the first paragraph of this section, last sentence, to insert after " scenario represents " something that says this worker is the critical group or maximumly exposed individual under this use (e g , " scenario represents the maximumly exposed individual under the most likely future use of Rocky Flats ") The reason is many will note that there are likely to be others on the site (even though the most effected of those others are the campers and hikers who are addressed in a separate analysis) and this statement clarifies that the worker has the highest risk or dose	We agree The text will be amended

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5	The other scenarios discussed lifetime exposure assumptions (up to 40 y for rural resident and 25 y for office worker) but for some reason this section does not specifically state a time period This is not critical as later in the table on page 16 it is listed	This information will be added to the text of the report for the wildlife refuge worker
6	There is an assumption that the fires burn off vegetation which, in turn, leads to higher airborne particulates and a higher radiation dose Fires of a sufficient severity to denude the site of vegetation would likely damage or destroy structures How is it that the assumed fires do not burn houses or crops? This consideration should be acknowledged in the report	This is a very good comment for discussion It is very likely that a large, heavily fueled, wind-sustained wildfire would consume everything in its path to some level of severity On the other hand, the working group could not ignore the ready possibility that a less intense wildfire could just as easily burn to the edge of an irrigated garden area and not destroy a significant portion of the crop It is important to recognize that the grassland fires experienced at Rocky Flats have not been high intensity fires, but they have on occasion consumed a reasonably large area before being brought under control The report will be modified to acknowledge that fires could damage structures and gardens to the extent that they could become uninhabitable or unavailable for some period of time following the fire
7	The relatively high level of irrigation (assumed to be 1 meter per year) is necessary to grow the hypothetical plant foods But fire severity and frequency would likely be much lower in cultivated, irrigated land than in open prairie This circumstance should be discussed In addition, the high assumed rate of irrigation would greatly increase plant recovery after a fire The report should acknowledge this consideration	Again, the reviewer is correct on both points if the assumption is made that the entire landscape surrounding the garden is irrigated to the same extent The scenario, however, does not assume grass cover on the areas occupied by the ranchettes, suggesting that native vegetation would be present instead Whether this is a realistic assumption could easily be argued but it is plausible This point will be discussed in the report
8	The assumptions involving hypothetical fires are contradictory since it is assumed that the fires consume vegetation, yet plant foods grown on-site are eaten as food Consequently, it is recommended that the "prairie fire" scenario for the rural resident be revised by comparing the radiation doses from the plant food ingestion pathway and the inhalation pathway If the dose from the inhalation pathway is larger under assumed fire conditions, then the plant food pathway should be ignored, alternatively, if the plant food pathway is larger under assumed fire conditions, then the incremental inhalation exposure from the hypothetical fire should be ignored However, it is a gross overestimate to assume both the consumption of	This comment expresses the same tenets as comment #6 above The response is the same, under a catastrophic wildfire scenario, the resident would have neither domicile nor garden, however the severity of grassland wildfires is not typically that extreme, at least not as observed at Rocky Flats The working group will acknowledge the possibility of a devastating fire, but will not modify the pathway analysis that was performed for this scenario

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	all vegetation by a fire and consumption of plant foods grown on-site	
9	The "rural resident" land use has some other assumption that overestimates dose and risk The very act of building a home and garden tends to dilute and disperse radioactivity through land use activities, such as excavation, construction of foundations, installation of water, sewer, and septic systems, plowing, clearing of land, establishment of roads and the like Most of the residual plutonium is in the top 2-3 inches of soil, and these activities would tend to mix the soil in a more homogenous manner The assumed mixing zone thickness (15 meters) of soil for inhalation and soil ingestion purposes is appropriate for some of these activities, but not for all In short, the very act of constructing a house and garden would lead to a further reduction of the concentration of any residual radioactivity and thereby reduce dose This consideration should be discussed in the report	The choice of a 5-acre owner occupied site, as opposed to a subdivision lot (which would be heavily developed) was based upon a presumption of little or no developmental dilution This is, of course a conservative assumption, since some development is likely to occur, but it is intended to address the uncertainty in how much development might occur in a prudent way No credit was taken for dilution of surface contamination through land development activities of the rural resident (building, digging, plowing, etc), a conservative assumption The tables in Section VI will be revised to include these kinds of considerations, as necessary The reader is also referred to the response to Reviewer 8's comment #14 for further discussion of construction-related dilution
10	The installation of roads would decrease airborne radioactivity and also decrease the effects of a fire The decreased effects from a fire would come from the road being a firebreak, from the pavement preventing radioactivity from becoming airborne before or after a fire, and from the road facilitating fire fighting efforts	The reviewer is correct in his assumption of reduced airborne radioactivity from areas that are paved or improved With sufficient density of roadways, the probability of a significantly sized fire would also be diminished, and accessibility for conducting fire-fighting activities would be improved far greater than exists now The extent to which this modifies the Rural Resident scenario is not easily quantifiable, but does illuminate the conservative nature of the calculations, as related to the 90th and higher percentile mass loading estimates
11	The assumption that residents could remain on site for as much as 24 hours a day for 350 days a year for 40 years is a clear overestimate It is much more likely that adult residents would have some form of outside employment, and this employment would lead to residents being off-site, perhaps 45 hours per week The income from outside employment would be needed to pay for utilities (irrigation, water, sewer, telephone, power, gas, etc), property taxes, off-site foodstuffs (meat, milk, grains, etc), and other cash expenses It is also likely that children would attend school, in keeping with public policy The notion that site residents would remain on site for 40 years without leaving is not plausible While site	For the point estimate risk assessment, the choice of 350 days/year reflects the Agency's policy for characterizing the reasonable maximum exposed individual For the probabilistic risk assessment, the 350 days/year value is assumed to be representative of the maximum of a triangular distribution in which the most likely value is 234 days/ year, and the minimum value is 175 days/year (50% of time away from home) The exposure duration estimates are based on national surveys of population mobility The choice of 30 years reflects the Agency's policy for characterizing the reasonable maximum exposed individual, and corresponds to approximately the 90th – 95th percentile of the distribution

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	occupancy was handled as a probabilistic variable, even the possibility of near full time occupancy is very dubious	
12	In short, the rural resident land use has a series of unlikely assumptions All land use controls are lost, The Federal, State, and municipal governments do not intervene, Farms are constructed with a size of 5 acres, Construction for homes and roads do not affect the residual radioactivity despite the excavation and grading for roads, utility pipes, and buildings, These farms produce sufficient income to pay taxes and utility costs, The farm residents do not necessarily have outside employment, Children spend most of their time on-site and may not attend school off-site, Irrigation is adequate for growing vegetables, which are part of the resident's diet, Fires occasionally affect the farm, notwithstanding the irrigation levels, The municipal fire departments do not exist or (alternatively) are unable to fight the fire, Farm roads and streets do not act as firebreaks or otherwise facilitate firefighting, After a fire, airborne dust is elevated, Irrigation does not affect the regrowth of vegetation, and Despite the fires consuming vegetation, structures and homes are not affected Taken as a whole, these assumptions are quite unlikely	The agencies recognize that the Rural Residential scenario that was used for these calculations is conservative The agencies do not consider this scenario to be a farm that would sell crops for income Rather, this is a 5-acre residence with a large garden for home produce There are several examples of residences of similar size in the vicinity of Rocky Flats and in other portions of the Denver Metro Area Potential grassfires would not be envisioned to be of a magnitude to damage structures
13	The Office Worker scenario assumes that a fire would burn all vegetation but not damage or destroy the building While reasonable land management would be expected around an office building and this management would likely control an area a few acres around the buildings to landscape the building, construct parking lots, minimize fire hazards and ameliorate post-fire impacts But these same land management steps would reduce airborne radioactivity from non-fire situations In short, the assumption that a fire would burn the vegetation without destroying buildings is a dubious assumption But the assumption that buildings are protected without a reduction in airborne dust from the office land use is equally	The working group did not spend as much time developing the scenarios for the office worker or open-space user as it did for the wildlife refuge worker and rural resident Neither of the former scenarios was considered a reasonable land use scenario in light of then pending, now final, legislation That said, the reviewer is correct, the consequences of a fire near an office building will not be severe If one assumes minimal land improvement around the office building as is frequently practiced in many industrial parks in this area, it is not difficult to envision prairie landscape very close to the building In that scenario, the mass loading following a prairie fire could be reasonably well

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	dubious	described by the same mass loading as is used in the Wildlife Refuge Worker scenario The location of the office worker would not necessarily be one where the worker is immersed in the maximally impacted region of the airborne plume, however Adding to this, in an energy-conservative environment, the amount of air that is actually admitted to the building and its impaired quality are likely overstated in the calculation It is clear that the calculated RSAL for the office worker is more conservative than even those calculated for the rural resident and wildlife refuge worker
14	The Office Worker scenario does not examine consider the maintenance or landscaping of the office building However, the scope and duties for a building maintenance job are similar to those of wildlife worker Consequently, the likely impacts to an office maintenance employee have already been considered, albeit under a different scenario This section should discuss those employees (under this scenario) that may spend time out of doors and specifically state they are considered under the other scenario or quantitatively or at least qualitatively discuss the difference from the "office worker"	The working group agrees that the office worker definition excludes the maintenance worker who might spend much of the time outdoors in a setting similar to that for the wildlife refuge worker The text will be modified to ensure that this issue is captured
15	It might be argued that a wildlife worker worked all over the site, while an office maintenance worker worked only in close proximity to the buildings for which he or she is responsible However, the amount of excavation required to build an office building and parking lot would significantly reduce the soil concentration of any residual radioactivity through soil mixing Thus, construction activity would tend to offset the possibility that an office building was located in an area with elevated plutonium concentrations	See response to Reviewer 7's comment # 9 concerning dilution of contamination due to excavation and soil mixing
16	Comparability to Other Cleanups These RSAL calculations show cleanup criteria with dose and risk that are much lower than the dose and risk from cleanups of sites involving radium At these sites, a cleanup criterion of 5 pCi/g is typically used, the sites at which this criterion have been used include Montclair (NJ), Landsdowne (PA), Radium Chemical (NY), Denver Radium (CO) and numerous uranium mill tailings sites Consequently, why should the dose and risk after cleanup at Rocky Flats	The agencies focused on site-specific conditions and potential future uses that were specific to Rocky Flats Assessments conducted at other sites had their own specific approaches Task 5 of the RSAL process addresses cleanup levels at other sites The cleanup level of 5 pCi/g Ra-226 is a contaminant-specific ARAR that was developed to guide the decontamination of properties under the UMTRA program The agencies do not believe this level was intended to be used as a benchmark risk

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	be lower for any particular scenario than at sites that are planned for free release After all, at Rocky Flats the most likely future land use is a wildlife refuge, and residential use is likely at many of these other sites It is recommended that this comment be addressed by inserting 5 pCi/g of radium-226 into the parameter sets for the computer codes and examining the dose or risk of the output	level that would guide the cleanup at all radiologically contaminated sites
17	Authors On the cover sheet, the names of the authors and their affiliations should be shown Similarly, the names of reviewers (both technical reviewers and reviewers within the management of the various organizations) should be listed separately, perhaps in an acknowledgment section	Since this report is a product of multiple agencies and many contributors, the working group and the agencies feel that it is most appropriate to list only the names of the agencies on the report As for the reviewers, some of the reviewers' names are listed with their comments Other reviewers, however, are anonymous and their names cannot be included
18	RESRAD Version On page 1, mention is made that RESRAD version 6 0 was used for calculations Was this version used by mutual agreement of the different organizations? The current version of RESRAD available from Argonne National Laboratory is Version 6 1 It may be that an agreement was reached to freeze the RESRAD version because of the length of time required for the calculations and to avoid rework simply because a new RESRAD version became available If there was such a "freeze" agreement, it should be mentioned	When the agencies started the process of revisiting the RSALS, RESRAD 6 0 was the latest version available RESRAD 6 1 has only minor changes relative to 6 0 The text will be modified to reflect that the version of RESRAD was "frozen" during the process
19	Dose Factors Dose conversion factors are discussed frequently within the document This document uses "updated dose conversion factors" from ICRP report 60 and later dosimetry The problem with this usage is that DOE, NRC, EPA, and the State of Colorado all officially use EPA Federal Guidance Reports 11 and 12 for dosimetry, and these documents are based on ICRP reports 26 and 30 For example, the NRC "Decommissioning Rule" specifies an annual dose limit of 25 millirem effective dose equivalent, the term "effective dose equivalent" is a term defined in ICRP 26 and 30, but not in ICRP 60 and later reports Dosimetry from ICRP 26 and 30 are heavily incorporated into a host of EPA, NRC, and DOE requirements, including (but not limited to) 40 CFR 191, 40	Comment 19 indicates that there is no regulatory precedent for use of the dose factors from ICRP 60-72 However, the agencies believe that there are several advantages to using ICRP 60-72 dose factors ICRP 60-72 embodies improved science (more precise biokinetic models of the respiratory system and more accurate apportionment of dose to the gastrointestinal tract) This has the effect of reducing uncertainty The biokinetic models and human and animal database used in the development of ICRP 60-72 are the same as those used in the development of the risk coefficients in Federal Guidance Report 13/HEAST Use of ICRP 72 dose factors assures consistency with use of the latest HEAST risk factors, whereas use of ICRP 30 dose factors does not

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	CFR 192, 40 CFR 61, 10 CFR 20, 10 CFR 835, and DOE 5400 5 All of these regulations specify or imply the use of organ weighting factors and other details, which are exclusively used in ICRP 26 and 30 dosimetry The usage of dose factors other than those specified in these regulations raised a host of issues as to whether the requirements are, in fact, being complied with Further, the "updated dose conversion factors" have not been officially approved by EPA, since EPA has not withdrawn Federal Guidance Reports 11 and 12 Consequently, the use of ICRP 60+ dosimetry without clear-cut official approval is problematical, and there is a serious policy question about the development and use of dose factors at individual sites (DOE, NRC, EPA) in an *ad hoc* manner	ICRP 72 dose factors were specifically developed to be applied to members of the public exposed to environmental contaminants, as opposed to workers exposed under more carefully controlled conditions (all previous ICFP dose coefficients were developed for application to workers) It is likely that quantitative estimates of uncertainty will be computed for the biokinetic models and human and animal data used in ICRP 72 computations (ORIA is tasked with developing quantitative estimates of uncertainty for the FGR 13 risk coefficients) With respect to the regulatory issues The dose based RSAL is not a regulatory cleanup level, although it may be used to influence the development of a cleanup level It is highly likely that the risk based RSALs (using FGR 13 risk coefficients) will be the selected RSALs The DOE site annual compliance report and the derivation of RSALs will be kept separate Of course, all site compliance calculations of dose will continue to be performed using ICRP 26/30 methodology, as required by DOE Orders
20	Presentation of Results The authors do an excellent job of factually presenting rationale, assumptions, parameters, calculations and sensitivity analyses in a scientific manner In doing so, they have developed a very credible report However, they should also take as much care in presenting the results Clearly, these analyses and the results are probably only good to one significant digit at best The results provide for example in Tables VI-1, V-2, V-3, V-4 and V-7, as well as in the Executive Summary, should have only one but certainly no more than 2 significant digits More than 2 significant digits portray a precision that greatly exceeds the knowledge base If for some reason, it is felt necessary to maintain the digits for calculation accuracy, at least place a footnote on each table indicating that the "analyses only justify one significant digit but are presented as calculated because " This should also be discussed in Section VI	Calculated results will be rounded to 2 digits and the tables will include the following footnote "Analyses only justify one significant digit, but values are presented with two digits for comparison purposes " Two significant figures will help compare and distinguish values for different radionuclides that were calculated using input parameters that have the same amount of inherent precision The amount of significant figures can be considered when risk management decisions are made to select final action levels
21	Sensitivity Analysis	As stated in the first sentence of Section IV-1,

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	In Section IV, it is surprising that the sensitivity analysis feature of RESRAD was not used for this work	Sensitivity Analysis Process, it was
22	Page 3, third bullet the EPA rule was never formally proposed or promulgated In fact, EPA withdrew the draft rule from review at the Office of Management and Budget prior to its publication as a proposed rule in the Federal Register	The working group concurs with the reviewer, the text will be modified
23	Page 3, last complete sentence at the bottom of the page This sentence should be reworded to read as follows "Earlier versions of RESRAD were used by the agencies in 1996, later, the Risk Assessment Corporation modified RESRAD for its own use "	No change will be made to this sentence It is a true statement that the Risk Assessment Corporation (RAC) "used" RESRAD It is beyond the scope of this report to explain how RAC used RESRAD or whether it was modified by RAC
24	Page 4, Second bullet In the last sentence of the bullet, there is a discussion that EPA guidance requires consideration of the maximally exposed individual Both NRC and DOE also require this consideration within their respective regulatory frameworks	The text will be modified
25	Page 7, last sentence in the first paragraph change the last part of the sentence to read "the Wildlife Refuge Worker scenario represents the maximally exposed individual from the most likely future use of Rocky Flats "	The text will be modified
26	Page 7, second paragraph The assumption that residual radioactivity is present at the entire site at the RSAL level badly overestimates the radiation exposure of workers, since most of the site has little or no plutonium	See response to Reviewer 3 comment # 3
27	Page 7, second and third paragraphs It is likely that the number of wildlife workers at Rocky Flats would be small, and the small number of workers would prohibit an on-site childcare facility because of economic considerations Specifically, there would not be enough workers to make a childcare facility economically viable	As stated in the text, a childcare facility at the refuge is not considered
28	Page 9, first paragraph in section b There is a discussion of periodic wildfires, which would "burn off accumulated vegetation " How do the fires burn off the vegetation without burning off the homes and crops?	Most grass fires that impact the Front Range of Colorado are not of a magnitude that would threaten structures The working group considered a plausible outcome from a grass fire to be a burned contaminated area immediately adjacent to an irrigated garden plot whose growth would be little affected by the aftermath of the fire yet be subject to wind-blown dust from the burned area
29	Page 11, second paragraph for the Open Space User Scenario There is a brief discussion of	Based on experiences with grass fires that occur at Rocky Flats, the extent of the burned land is

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	increases in airborne particulates following fires It should be noted that, after a fire, visits might increase from curiosity seekers but decrease over the longer term because of the adverse smell	relatively small, the land recovers from the effects of a fire relatively rapidly Any residual odor also diminishes rapidly
30	Page 17 In the second to last sentence in the "Direct Dermal Absorption Contact Pathway," mention should be made of the current usage of municipal water systems in the area A similar comment should be inserted in the last sentence of the second paragraph in the section entitled, "Ingestion of Surface Water, Ground Water, and Food "	Most residences east and southeast of Rocky Flats rely on municipal water, but there are homes in the vicinity of Rocky Flats that are more widely spaced and get water from private wells
31	Page 18 In the first paragraph of the section entitled "Solubility of Plutonium and Americium," the discussion of RESRAD in the fourth sentence is in error This sentence states "The RESRAD groundwater transport calculations treat plutonium and americium separately, and do not adequately represent the behavior of weapons-grade material containing both " RESRAD uses distribution coefficients (Kd) to describe the partitioning of radionuclides in solution The user specifies the distribution coefficients by inputting them or using default values Alternatively, the user can specify solubility limits to describe the behavior of aqueous radionuclides, and RESRAD will calculate a Kd using the specified solubility limit The problem mentioned here arises when the wrong Kd is input by a user If the dissolution of Americium is similar to that of plutonium, they would have the same Kd This paragraph needs to be rewritten to indicate that the behavior of americium is atypical because of its association with plutonium in many on-site areas However, there were separations of americium from plutonium at Rocky Flats, and there is a potential for americium to be present without an association with plutonium But since most of the americium in soil (including the 903-B pad) is associated with plutonium, it is correct to use similar Kds for both elements A clarification of this topic should be made in the report, and references to Kd or other geochemical measurements should be inserted	The reviewer is correct in stating that the section needs to be rewritten to better reflect the intent of the statement It was not intended to imply that there was a limitation in RESRAD that restricted the proper use of the distribution coefficients Instead, it was intended to illustrate exactly what the reviewer states – that the americium is associated with the plutonium in much of the contamination, and needs to be treated as plutonium when considering its behavior in water
32	Page 19 Just above section IV-1, there is a statement, "EPA policy recommends against developing site-specific probability	See response to comment #37 from peer reviewer #2

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	distributions for human health toxicity values " All Federal agencies have long used the linear, non-threshold approach to radiation effects on the assumption that the assumption prudently and conservatively addresses the possible effects of radiation at low doses This usage has been made in the full knowledge that this theory probably overestimates health effects Consequently, the slope and dose conversion factors used in this study probably overestimate effects, as well	
33	Page 28 There is considerable discussion about dose conversion factors and their usage, as well as the selection of dosimetry from ICRP 60 and later publications The more recent dosimetry has not been accepted by Federal or State agencies for general use, although their use has been approved on a case-by-case basis in a few instances No Federal agency (EPA, DOE, NRC, OSHA) has given public notice of the revision of its radiation protection rules to change rules from the dosimetry in ICRP 26 and 30 to that of ICRP 60 EPA has not withdrawn Federal Guidance Report 11 and 12 (which are based on ICRP 26 and 30 dosimetry) in favor of the more recent models All Federal agencies have agreed to use Federal Guidance Reports 11 and 12 for radiation protection purposes, although the Federal Agencies lead by EPA are reevaluating the possible use of the ICRP 60+ dosimetry but have not made any general recommendations at this time So, because of the difference in organ weighting factors (discussed in the second full paragraph on page 28) there is a potential for regulatory disconnects between different dosimetry models However, the authors of this draft report have identified the reason for the fact that ICRP 60+ dosimetry is not used widely within the Federal government In the third full paragraph on page 28, they observe "However, the working group has examined the relative changes in these parameters and has concluded that the parameters being examined in detail would not have changed " On a larger scale, this is a succinct description of why ICRP 60+ dosimetry has not been embraced by the Federal	The agencies agree with the comment Even though there are regulatory "disconnects", the end-result for calculating RSALS is insignificant See also the responses to this reviewer's comments #19 and #38

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	government – there are very significant costs and very little benefit in the way of health protection And in the case of the RSALs, it appears that the difference in dose factors does not change the RSAL in a significant way	
34	Page 30 In the discussion about the "Outdoor Time Fraction" parameter, the correlation between the indoor and outdoor time fraction should have been a negative correlation, since, as the text indicates, time spent outdoors cannot be spent indoors In the discussion on the "Depth of Roots," the choice of setting the depth of roots equal to the contamination thickness is proper, because in the process of plowing and tilling the soil of a garden, the residual radioactivity would be homogenized throughout the thickness of the contaminated zone and the soil mixing layer	The point is well taken The RESRAD calculations will be redone using a correlation factor of –0 999 for indoor and outdoor time distributions, among other changed parameters
35	Page 31 In the discussion of the "Mass Loading for Inhalation" parameter, an assertion is made that recent air monitoring "does not adequately represent potential perturbations to the annual mass loading that might be experienced by a future user at Rocky Flats " Shouldn't the monitoring data reflect the ambient conditions? Have there not been wildfires, both on and off site? Are there not a large number of vehicles driving onto the site with workers? Do these fires and vehicles not "perturb" the airborne particulates at the site, and introduce more dust into the air than would otherwise be present? After closure, wouldn't the large number of vehicles traveling to and from the site decrease in a dramatic way? While the use of a distribution of values is prudent, the text in the report is in need of some revision	The issue to be discussed here is whether the recent air monitoring for PM-10 and TSP adequately reflects the activities that go on at the site The air monitoring for particulate mass loading is performed at locations that would not necessarily capture the influence of Rocky Flats activities *per se*, but is instead intended to capture samples that represent the regional air quality in this area If the modeling is to adequately represent the effects of actual land perturbations on dose and risk, the inputs need to reflect the direct influence of those activities The working group attempts to capture those potential activities by estimating the baseline influence of such activities relative to the present regional observations This results in an increased baseline mass loading because the "sampling" would be done at a receptor who is closer to the activity than is represented by a regional air monitor The text will be clarified regarding this point
36	Page 42 In Section IV-6, there is no discussion of the rate of irrigation affecting airborne particulates If the site were to be irrigated at the assumed 1 meter per year rate, the airborne dust would be significantly reduced	The scenario assumes irrigation is used only for the garden, not for lawn or landscaping use Dust would be suppressed in the garden area by this irrigation, but not in the surrounding areas See the discussion in response to Reviewer 7's Comment # 7
37	Page 43 In the paragraph at the bottom of the page, a better description of the administrative details of the wind-erosion studies should be presented The text should read "Under contract with [DOE, Kaiser-Hill, etc] the xyz corp conducted a wind erosion study "	The reviewer is correct in noting that this attribution is missing The text will be modified appropriately

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	corp conducted a wind erosion study "	
38	Pages 45-48 This discussion does not mention that EPA used ICRP 26 and 30 dosimetry to produce Federal guidance Reports 11 and 12, and that DOE, and NRC have agreed to use the EPA reports for radiation protection purposes EPA has not issued any successor to those reports or announced their withdrawal from use	Comment 38 indicates that DOE is obligated to compute doses for annual compliance reports using tissue weighting factors from ICRP 26 and dose conversion factors from Federal Guidance Report 11 (based upon ICRP 30) As stated in the response to Reviewer 7's comment number 19, the DOE site annual compliance report and the derivation of RSALs will be kept separate Of course, all site compliance calculations of dose will continue to be performed using ICRP 26/30 methodology, as required by DOE Orders
39	Page 48 In the last sentence of the first paragraph, the text should read "The current NRC, State of Colorado, EPA, and DOE radiation regulations relevant to determining total effective dose equivalents are based on ICRP 30 "	The text will be modified to incorporate this suggestion
40	In the third paragraph of page 48, there needs to be an expansion of the discussion involving the inhalation class of plutonium The text might be something like " disagree on this point (on the basis of environmental data at Rocky Flats and elsewhere, DOE advocated use of the slowest absorption type, S type but because EPA felt that this data did not provide absolute certainty, M type should be employed for conservatism) All Parties "	See response to Reviewer 2, comment #16
41	Page 50 Just above section V-2, an assertion is made that the americium to plutonium activity ratio is 1527 What is the correlation coefficient for the linear regression of the data from the 903-B Pad characterization?	The activity ratio used in the draft report compared HPGe gamma measurements for Am to alpha spectroscopy results for Pu A linear correlation of Pu alpha spectroscopy to Am alpha spectroscopy data in the 903 Pad characterization report yields a Pu Am ratio of 5 815 (Am Pu ratio of 0 17) The correlation coefficient (R) for the linear regression is 0 89 The text will be modified
42	Page 60 In the very last table entry on this page, the failure of the EPA risk methodology to consider radioactive decay will definitely overestimate risk but probably not at Rocky Flats There are no significant short lived radionuclides, and future ingrowth of radionuclides in decay chains is not significant Nonetheless, the text should read that this "will over-estimate risk" rather than "is likely to	Text will be modified

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	over-estimate risk ”	
43	Page 61 Tables VI-1, VI-2, VI-3, VI-4, and VI-5 – the following concerns should be added to these tables, as appropriate Assumption that there are foodstuffs available to a rural resident notwithstanding a simultaneous assumption that the assumed farm is denuded of vegetation Assumption that a heavily irrigated (1 meter per year) agricultural area is susceptible to fire to the same extent as unirrigated areas and that post-fire dust levels in irrigated areas are also comparable to unirrigated areas Assumption that irrigation has no effect on vegetation regrowth after a fire Assumption that buildings (rural resident home and wildlife worker office) are not destroyed by fire despite all vegetation being burned Assumption that the establishment of buildings (and utilities-- sewer, water, gas, electricity, etc) will not mix, bury, and otherwise dilute and disperse residual radioactivity during construction	The tables in Section VI will be revised, as appropriate **Section 6 is now Section 7*
44	Page 67 In the discussion of contaminated zone thickness, the text should explain that plowing or tilling of soil for agricultural use will mix the soil, and that 0 15 meters is a reasonable approximation for the depth of mixing	The rationale will be modified to read, “Accounts for the possibility that all contaminated dust can eventually be inhaled Surface soil profiles at Rocky Flats indicate that 90% of the contamination is in the upper 15 cm No credit was taken for dilution since the working group considered only limited tilling in a garden and not large-scale farming activities Tilling will mix soil and 0 15 m is a reasonable approximation for the depth of mixing ” The discussion to which the reviewer refers has been removed from the text This soil depth was chosen because it represented the depth to which surface deposited contamination has been typically found at concentrations significant to this analysis This is captured in the discussion of chapter 4
45	Page 72 In the first table entry, the word “Work” should be inserted before the word “time ” The text should read, “<u>Time on-site</u> Worker is assumed to spend 100% of his/her **work** time on-site within the approximately 300 acres that is contaminated above 10 pCi/g ” Based on the data presented here, the outdoor exposure for the wildlife workers should be	See answer to Reviewer 7’s comment # 3 above

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	evaluated for reduction	
46	Page 72 In the discussion of the possibility of a day care facility for children, it is unlikely that there would be enough wildlife workers employed at the site to make an on-site day care facility economically feasible A provision for a day care facility for people not employed at a wildlife refuge is a commercial use not consistent with the proposed status of the site as a wildlife refuge	We agree
47	Page 74 There is an error in the stated RESRAD occupancy factors for Exposure Time and Indoor Time Fraction For RESRAD, there is no occupancy factor For RESRAD, the indoor time fraction for occupational exposure should be about 20 hours per week divided by 168 hours per week or 0 12, which represents the fraction of a year spent indoors on-site	The appropriate adjustments were incorporated in the indoor and outdoor time fractions The table will be corrected
48	Page 75 In the discussion of Outdoor Time Fraction, the RESRAD parameter should be about 0 12, not 0 5 This input is the fraction of a year spent on-site, outdoors	See response to comment # 47
49	Page 77 The assumption that an open space user will spend 100% of his/her time in 300 acres of a 6400-acre tract is overly conservative The exposures should be scaled be dividing by a factor of 10 to account for this circumstance	The working group agrees that the assumption is conservative, but does not believe it is overly conservative Given the passage of the Congressional Act making Rocky Flats a wildlife refuge, the open space user should be regarded as a wildlife refuge visitor A typical wildlife refuge visitor differs from a park or open space user Typically, visitors to wildlife refuges are not allowed free access to an entire site, and activities such as mountain biking are not allowed Both of these uses are not consistent with the primary purpose of the refuge, which is protection of wildlife habitat and populations Rather, visitors are usually constrained to existing walking trails Using this as a basic assumption, CDPHE calculated an activity-weighted exposure unit for the wildlife refuge visitor of approximately 10 acres
50	Page 79 The RESRAD Outdoor Time Fraction is not correct With the exposure defined as 100 visits per year and 2 5 hours per visit, the total time is 5 hours per week, or, for the RESRAD input, 0 03 (The RESRAD input is the fraction of a year spent on-site, outdoors)	The appropriate factors were used in the calculation The table will be corrected
51	Page 82 The RESRAD Occupancy Factor and Indoor Time Fraction are not correct There is	The appropriate factors were used in the calculation The table will be corrected

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	no "occupancy factor" in RESRAD The indoor time fraction will be 8 hours per day, 50 weeks per year, or 24, which is the fraction of a year spent on-site, indoors	
52	Appendix A Page 2 The thickness of the contaminated zone is appropriate set for 0 15 meter This is the likely depth for plowing, and, if one assumes agricultural use, plowing is certain The same value for thickness of roots is appropriate, with the understanding that this may overestimate root uptake of some crops	The working group agrees with this comment No credit was taken for the dilution that would occur in the limited garden area
53	Appendix A Page 3 Setting the soil mixing layer to 0 15 meters is appropriate, if agricultural activities are assumed It is likely that plowing the soil would mix the soil over this depth	See response to comment # 52
54	Appendix A Page 5 In the discussion of mass loading of dust in the air, it is possible that the dust in air at the site would decrease after closure because of the decrease in human and vehicular traffic There are presently hundreds of people and vehicles driving and walking through the site After closure, this will greatly decrease Consequently, there is a possible reduction in airborne dust from the current measured values after site closure This possibility should be discussed in this section	The reviewer is correct that site activities will decrease However, it is not thought that the regional dust loading presently being measured is particularly influenced by Rocky Flats activities As noted in response to comment #35 from this reviewer, the dust loading used in the modeling calculations needs to be representative of the actual activities that are being modeled The text will be clarified to reveal this point in more detail
55	Appendix A There is a brief discussion about irrigation decreasing airborne dust for the rural resident The assumed irrigation will decrease dust by increasing the growth of vegetation and increasing soil moisture Further, in the event of any fires, irrigation would decrease the extent and severity of fires, and irrigation would grow back much faster because the irrigation would facilitate the regrowth of plants	As stated in response to comment #36 by this same reviewer, the working group assumed irrigation would be applied only to the garden area
56	Appendix A There has also been an extensive and commendable effort to identify airborne dust levels both near Rocky Flats and at other sites within Colorado This data is presented in summary form in Appendix F	The working group appreciates this comment It will however attempt to better explain the relevance of this information to the mass loading calculations
57	Appendix A Page 22 Are the concentration units mg/day throughout this table? The units should be shown	The units mg/day will be added to the table
58	Appendix A Page 51, As discussed above, the possibility that a person is present on-site for as much as 24 hours per day for 350 days per year is quite dubious While the parameter is	See response to comment #11 above EPA recommends an RME of 24 hours per day, 350 days per year for a Residential scenario It is

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	handled in a probabilistic manner, the distribution should be examined to verify that it is sound	true that most residents will be away from home more often than this length of time, however there are citizens who are elderly or disabled and leave home very infrequently
59	Appendix A Page 54 There is an extensive discussion of the exposure frequency for a wildlife worker However, there is residual radioactivity in only a small portion of the site, and it is incorrect to assume that all of the time "on-site" is in an area where there is residual radioactivity	The RSAL calculation, appropriately, focused on the limiting condition, rather than a realistic condition in assuming that the wildlife refuge worker would spend all of his time on-site in the most contaminated area As discussed in the response to Reviewer 7's Comment 3, we do not believe that the size of the area used to calculate the RSAL was unreasonable
60	Appendix B These equations do not account for radioactive decay This circumstance does not affect the calculations at Rocky Flats in a significant way	The reviewer has correctly noted that omitting consideration of radioactive decay in the risk calculation will have little effect on the result Ingrowth is also not considered in the Standard Risk equations, and has perhaps the potential to affect the results even more than decay The working group addressed this in its selection of an americium to plutonium ratio which is very near the equilibrium value for weapons grade plutonium, thus assuring near maximum ingrowth in its initial conditions Also, the risk equations are used to calculate risks based upon radioactive inventories and environmental conditions which are typical of the early period of contamination, when weathering and radioactive decay have not significantly reduced the level of contamination, thereby computing a conservative RSAL Finally, the long half lives of the plutonium isotopes and steady state conditions (equilibrium) of the americium inventory assure that there is little change in exposure conditions over the relative short exposure durations considered These aspects of the problem effectively compensate for the limitations of the risk equations, as used at Rocky Flats During later deliberations by the working group, a decision was made to use the maximum in-growth of americium in the americium to plutonium ration in the group's calculations of sum-of-ratios RSALS This provides the most protective example of a calculated RSAL using this method It should be noted further that in-growth does not reach an equilibrium state, instead, the in-growth reaches a maximum in about 8 decades following production of the weapons-grade plutonium, and then decreases over time

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61	Appendix C Page 1 in the first bullet, the shape affects the direct gamma radiation exposure pathway, but not the other pathways For shapes other than circular and for exposure positions other than in the center, the direct gamma radiation dose is lower Since direct gamma radiation is not significant at Rocky Flats, this assumption does not have much of an effect	The point is well taken The feature of RESRAD that enables non-circular shapes and non-centrally positioned receptors to be considered is very useful, particularly when modeling smaller areas of contamination In addition to the point made by the reviewer that the external exposure component of total exposure is small in this calculation, there is also the fact that the area modeled for plutonium and americium contamination is quite large in this problem It has been our experience when using RESRAD that the gamma exposure pathway reaches its limiting value (saturates) at relatively small areas under conditions of ideal geometry - on the order of a few hundreds of square meters The area modeled at Rocky Flats is many times larger than this, suggesting that the shape of the contaminated area and positioning of the receptor are not important unless the receptor is positioned close to an edge of the contaminated area
62	Appendix C Page 2 In the second paragraph, the discussion of the area correction factor is wrong There was a model change in the "area factor" between RESRAD 5 61 and RESRAD 6 1 But since the area factor calculation is different between the two versions, the conclusion of the paragraph is correct " the results [of the previous work] are not directly comparable to the results of this task "	The reviewer is correct in his reference to Appendix D page 2 The statement on page 2 should reflect that the calculation of the area correction factor was not the same in the RESRAD code used in 1996 This error will be corrected in the text
63	Page 5 The input data includes distribution coefficients for Pu, AM, and U Were these measured? What is the reference?	The reviewer refers to Appendix D, page 5 The distribution coefficients stated in this table are those used in the 1996 RSAL calculations Since the water pathways were not turned on for the calculations of the RSAL, these distribution coefficients were not used Protection of surface water quality will be considered separately from the RSAL calculation
64	Appendix G The discussion on page 3 compares actual air monitoring data and the RAC modeling results This presentation is very helpful	Considerable confusion appears to exist as to the reasons for the differences in values of RSALs calculated by the RAC methodology and by the working group's approach for a similar scenario There has been speculation that RAC's lower numbers are due to selection of more extreme scenario and exposure conditions (maximally exposed individual) versus those values used by the working group (reasonably maximum exposed individual)

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		From our work with the RAC scenario, we are convinced that the single most important factor, by far, which is responsible for the majority of difference in computed RSAL values between RAC and the working group, is the use by RAC of a calculation algorithm for annual average mass loading in air, following a fire, which results in very high values of mass loading at the upper end of its distribution It is obvious from comparing the RAC dose components (where the inhalation pathway completely dominates) with those of the working group (where the soil ingestion pathway contributes most) that the choice of mass loading value is the critical difference, in spite of all other scenario differences Since the working group chose to use a mass loading distribution based upon empirical data, as opposed to a calculation algorithm, we wanted to see how the critical numbers of RAC's distribution of calculated values would compare with empirical data for annual averages of small particles in air EPA's database offered a ready opportunity to compare PM10 data for annual averages as measured in the US and elsewhere, with the numbers generated by RAC's algorithm We felt that it was important to present this comparison in an effort to clear up misunderstanding Based on this comparison, we are convinced that there would be minor differences in RSAL values computed by RAC and the working group if RAC had used an empirically measured mass loading distribution (with empirically measured post fire data as well) similar to the one we developed

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1	Pp 1,49 The table of dose and risk calculations for various scenarios needs to show numbers for the resident rancher under the CERCLA risk levels, in order to make the Resident Rancher scenario readily comparable to risk calculations for the other scenarios Also, it would be valuable to have a column for the 15 mrem/y dose level used in 1996 by RAC in 2000	The agencies had committed to model the Resident Rancher scenario as described in the RAC Independent Calculation using RESRAD 6 0 for the purpose of comparing the computational methods employed by RAC to those employed by the agency work group The agencies did not agree to perform risk calculations for the Resident Rancher scenario using the EPA risk equations, which would be a significant amount of additional work The agencies considered that the Rural Resident scenario with 5-acre lots was a more realistic land use in the event of institutional control failure, representing an RME individual The proximity of Rocky Flats to a major metropolitan area that has encroached from the south, east and north also makes the development of Rocky Flats as a full-scale ranch unlikely
2	p 4, ¶ 2 Correct "principle" to "principal"	This change will be made
3	p 7 There is nothing specifying the number of years the refuge worker is expected to work at the site (this info is given on p 16)	This information will be added to the text of the report for the Wildlife Refuge Worker
4	p 9 Re the Rural Residential scenario, is it realistic to assume this person will be on the site 24 hours/day for up to 350 days/year but outdoors no more that 20% of the time?	It is reasonable These data are taken from EPA's default central tendency recommendation for residential exposure The percent time indoors includes a person's activities year-round in both warm and cold seasons, including eating, sleeping It is certainly true that a person could be outside for longer periods during warm seasons, but those longer time periods will likely be offset staying indoors more frequently during colder periods
5	Pp 17-17 More detail and documentation is needed to support the assertion that onsite water would not be used under any scenario considered Could damming of streams provide enough water? Could this be supplemented by wells? One thing clear here is that the scenario selection precludes adequate attention to the to the water-use question What would it look like to calculate possible water use for the Resident Rancher or subsistence farmer scenario?	Given its very limited capacity, the shallow alluvium at Rocky Flats is not considered to be a viable source for drinking or irrigation water The Laramie-Fox Hills aquifer, located approximately 600 feet below the surface, is a regional aquifer The working group believes that water would have to be imported or pumped from the deep aquifer to support any agricultural or residential use of the land With respect to the availability of surface water for use at a ranch, preliminary results from the Site-Wide Water Balance Study indicate that post-closure conditions in Walnut Creek are likely to be much drier than they are today This is due to the fact that the site is purchasing water for potable use and that this water is discharging into entering Walnut Creek from both leaky pipes in the Industrial Area and from the

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		wastewater treatment plant This water use will end In addition, the impermeable paved surfaces in the Industrial Area cause precipitation to discharge directly into Walnut Creek via storm sewers These paved surfaces will be removed from the Industrial Area, which will make the creek's watershed to be much more similar to the more natural conditions found in the Woman Creek watershed In the Woman Creek drainage, the vast majority of precipitation evaporates rather than leaves the site as surface water
6	p 18, III-3 David Janecky, at a recent AME meeting, said he had found unusually high concentrations of Am in certain areas of the site I gathered from his presentation that the Am about which he spoke is above and beyond what would show up as daughter product of weapons-grade Pu Does the sum-of-ratios method for calculating RSALs account for these unusually high levels of Am?	David Janecky presented no new information regarding the possible origin of americium on the site, this was known by the individuals working on the 1996 RSAL report, and before The sole purpose of the sum-of-ratios calculation is to deal with varying relative concentrations of contaminants, such as documented by Dr Janecky The working group has calculated separate action levels for americium and plutonium, those action levels apply to any relative mix of the isotopic concentrations, through the sum-of-ratios calculation There may be some confusion on this issue because of the way the RSAL values are presented in the Executive Summary of the Task 3 Report There, the RSALs are presented as sum-of-ratios for the Am-to-Pu ratio observed at the 903 Pad The results are presented this way to be consistent with the presentation of results from the 1996 RSAL Report and from the work of RAC Also see response to Reviewer 3's comment #9
7	p 18, final sentence This sentence suggests that no adverse effects can be expected from movement of Pu in shallow groundwater Isn't movement of Pu in shallow groundwater a possible source of the 1997 exceedances to the state's Pu-in-surface-water standard?	There is no evidence to suggest that the values observed at monitoring location GS03 are from shallow groundwater, nor is there reason to believe that a shallow groundwater plume contaminated with plutonium would exist in that area Data from wells installed in the vicinity of GS03 indicate plutonium concentrations consistent with values measured in clean "blank" water samples submitted as part of the AME investigations Erosion modeling performed as part of the Actinide Migration Evaluations shows that erosional transport from even moderately contaminated surface soils can, under the right circumstances, cause concentrations in surface water to exceed the 0 15 pCi/l standard However, that modeling was performed on an "event" basis, and does not allow one to conclude *per se* that the underlying standard would be exceeded
8	p 21, lines 3 and 4 and elsewhere Please explain and demonstrate what is meant by	A health protective point estimate is a single value used in lieu of a distribution when available data are

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	selection of "a health protective point estimate"	deemed inadequate to create a distribution or where the parameter is considered to not be influential in significantly affecting the resulting calculation An example of a health protective point estimate would be to assume that, for the Rural Resident scenario, all homegrown produce is considered to be contaminated
9	p 25 What is the "outdoor time fraction" so insignificant?	The outdoor time fraction variable contributes to the dose from each of the exposure pathways Therefore, it is more likely to modify the total dose than many of the other exposure variables that appear in only one of the exposure pathways
10	p 27, ¶ 2 Where is Figure IV-4?	Figures were numbered and referenced incorrectly The text will be modified
11	p 44 Assuming we get a green light on the way the wind tunnel data has been used in this report, I will here raise two points First, in calculating mass loading from fire, the agencies should get data re possible climate change in the Rocky Flats area over the next century and beyond, as far as projections have been or can be made by, say, NCAR Is the area likely to be wetter or dryer, according to prevailing climatic trends? How might this data affect the possibility of fire and thus the understanding of mass loading in association with fire? Second, the information given suggests that a short-term calculation for a fire has been made, that is, one that assumes the continued utilization of controlled burns Since there is strong public opposition to controlled burns, what other alternative short-term calculation can be offered – that is, one that does not assume ongoing controlled burns? Then, with respect to the long term, what will happen regarding mass loading when the practice of controlled burns has ceased? There are two different ways of asking for attention to the absence of controlled burns The first assumes there might be an alternate near-term practice, the second that any attempt to offset the danger of fire will some day disappear and thus that the fire potential should be calculated assuming controlled burns are not happening	Regarding the first question The working group took the published guidance of the National Drought Mitigation Center as its basis for using the existing 35 years of validated site meteorological data in assessing the influence of precipitation on the land-use scenarios Regarding future prediction of change, in its global warming website, "EPA reiterates the warning provided by all climate modelers to people considering the impacts of future climate change *the projections of climate change in specific areas are not forecasts, but are reasonable examples of how the climate might change* " (EPA, 2001, http //www epa gov/globalwarming/climate/future/us climate html) Even if the working group had the appropriate tools to deal with future climate change, projections into the future regarding weather influences would require more changes to the scenarios than a simple change in mass loading parameters A shift in seasonally averaged temperatures in the Front Range area may result in significant changes in the types of vegetation, as well as significant changes in the number and intensity of storms, etc For example, on EPA's website, there are discussions that suggest shrub-like vegetation could be favored over the prairie grasses that presently abound, also there are projections suggesting more rainfall, but potentially drier soil One could even question the validity of the land uses themselves, depending on the severity of the changes Consequently, the parameters that would be modeled would change in ways that the

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		working group could not predict The working group chose to work within the confines of "reasonably foreseeable" land uses, as prescribed in CERCLA Regarding the second question We must first agree that the risk incurred by the aftermath of a fire is independent of the fire's cause, whether naturally occurring or man-made Secondly, we must recognize that the purpose of conducting controlled burns is not primarily for fire risk reduction, but for prairie grassland management The major contribution to fire management from controlled burns is to reduce the rate and intensity at which a possible fire might expand, not its frequency Once that basis is established, the question to be considered, and the one actually considered by the working group, is "what is the most conservative, and reasonably predictable, fire frequency, and what is its influence on dose and risk The "short-term calculation", i e , one in ten probability, turns out to be a more conservative calculation of fire probability than the other cases presented in this question Apparently, the report does not expand sufficiently on the range of possibilities explored by the working group Consider several possible approaches A wildfire on the site was considered a likely event Its probability in a given year on a contaminated area could be developed through a number of reasonable assumptions including Assume one fire a year (this frequency is more often than has been typically observed at the site) Assume one 300-acre parcel of land is significantly contaminated The probability of a fire on the contaminated 300-acre parcel can be estimated as 300/6400 per year, that is approximately 5% probability/year, or one fire every 20 years on the contaminated parcel There is no reason to assume preference of one area over another for naturally occurring fires We might observe additional fires near the perimeter roads, but those have no influence on the probability of fires in the contaminated areas Assuming the entire 300 acre parcel were to burn, it is not reasonable to speculate that the same parcel

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		would burn two years in a row The amount of fuel available the second year would not support a significant burn and, if prairie management were the driver, such an occurrence would not even make good sense This consecutive-year exclusion would have the net effect of reducing the influence of fires in any given multi-year risk calculation If fewer than 300 acres were burned, the remaining contaminated area could burn the next year, with the reduced consequences of the smaller exposed area (This multi-year exclusion was not exercised in the working group calculations) While this area-based probabilistic calculation was favored by at least one member of the working group, the group settled on controlled burns to establish the more predictable, and higher, frequency, since that ten-year rotation yielded fires at twice the rate of the wildfires To make the calculation more realistic under institutional control, one could assume that controlled burns would be conducted in areas removed from significant contamination The working group discarded this assumption recognizing that a wildlife refuge could continue even though institutional history was lost 2 One could also take an entirely different perspective and view the fire events as occurring randomly over the entire site with fires of the size and frequency of occurrence as are observed across the Front Range Based on data from the Colorado Forest Service for 1999, of 390 grass/wildfires reported in the Front Range, almost all were less than 1 acre, with seven reported between 1 and 6 acres and only one reported larger, at 352 acres Based on acreage, only 1 acre in a thousand would be expected to burn in any given year For a fire of 5 acres or more, the probability is far less than 1% per year, all other factors being the same The working group considered these data in its discussions and settled on the ten-year frequency (10% probability) as being a more reliable indicator It turns out also to be more conservative
12	Appendix A, p 6 ¶1, final The first sentence here seems to misrepresent the nature of RAC's work, which was not a peer review of the 1988 work but a independent analysis and calculation for RSALs for Rocky Flats	The reviewer is correct The text will be modified
13	Appendix A, p 9 ¶1, final sentence Please explain why zero rainfall was not considered a	An event in the Front Range characterized by zero annual rainfall would be disastrous without regard to

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	feasible condition to assess	the conditions at Rocky Flats, in part because it would have to be preceded by other very significant changes in climate Such an extreme assumption would be a distortion of any reasonable scenario representation, causing speculation far outside the ranges of available data or rational assumptions, and would misappropriate the process of estimating probabilistic risk to a "reasonably maximally exposed individual" Zero rainfall would be by definition, the 100th percentile rain-deficient condition, in other words an extreme event with essentially zero probability of occurrence Were the working group to consider such an unrealistic condition, the working group would have to adjust a number of scenario assumptions including the rate of homegrown vegetable consumption, the time fraction spent indoors and outdoors, the time spent on-site, the dust shielding factor for the building, etc , as well as related input parameters such as soil ingestion rate To understand the simple projections used to estimate the effects of deficient rainfall on mass loading, we need to keep in mind that we are already working with a semi-arid environment Using the same algorithm as used to calculate the 95th percentile effect of deficient rainfall would suggest an increase of 30-plus percent in the mass loading, compared to the 14 percent increase at 95th percentile deficiency Of course, the assumptions going into the algorithm would likely be invalid under conditions of zero annual rainfall, as would many of the conditions and assumptions in the land use scenario itself
14	Road construction Given that the legislation to make Rocky Flats a wildlife refuge includes provision for construction of a segment of the Northwest Parkway along the eastern border of the site, all scenarios for which the RSAL calculation is being made should include information of the condition of this portion of the site and possible effects of such construction	Large-scale construction projects such as road construction move vast quantities of soil and completely disrupt the soil in the area over which the projects are executed There would be no long-term increase in risk from the soils in the area of the construction project In fact, the result would be a net reduction in risk, because the relatively small quantities of contaminated soils would be mixed into clean soil and covered in a manner that limits the erosion potential to negligible levels The remediation performed on OU-3 is an example of such dilution, whether deemed desirable or not by a particular reviewing party

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		A more pertinent question could be asked regarding the short-term dose during the period of construction, actually only for a period during which the surface soil is either being disturbed or removed While this event is not considered in any of the land use scenarios, it is accommodated in the leading assumptions to the choice of the median soil concentration used to "seed" the probabilistic mass loading distribution In the initial investigation of the effects of soil disturbance activities that might play in a Rural Resident or Wildlife Refuge Worker scenario, small-scale construction and soil disturbance activities, of the type that would be supported by the specific scenarios, were considered These activities essentially doubled the presently observed air mass loadings for the years in which the activities were performed This resulted in the selection of a median mass loading of about 22 ug/m^3 for the starting mass loading distribution estimate For the purpose of discussion, consider in more detail the process of earth moving and filling The repeated scraping, filling, and compacting of the soil serves to dilute the actinides in the soil that is being worked The thin contaminated layer of several inches would be quickly covered and/or graded and mixed with larger volumes of uncontaminated soils, resulting in much lower actinide concentrations in the potentially exposed materials subject to wind and water erosion While the initial disturbance would involve fully contaminated soil, the disturbance would necessarily be of short duration prior to the soil being mixed and mostly covered Very little of the contaminated soil material would actually be available for suspension and erosion into the atmosphere Risk would be significantly reduced in such a scenario
15	On what basis do the authors of the Task 3 Report disagree with IEER's finding regarding the scientific validity for using the subsistence farmer scenario to calculate the RSALs for Rocky Flats? Why is it reasonable to reject this scenario, given the long-term danger posed by contaminants at Rocky Flats? Please note the detailed historical analysis of this scenario provided by IEER's full report	The agencies are obligated to make their decisions based upon established regulations and policy, which put forth a strong preference for basing cleanup decisions on the anticipated future land use An extensive discussion of these regulations and policies, and their application at Rocky Flats was presented in the Task 1 document, "Radionuclide Soil Action Level Regulatory Analysis", Revision 2, dated January 24, 2001 Further explanation was provided in the response to comments on that document IEER's December 2001 report describes a subsistence farmer scenario that has many

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		similarities to the working group's Rural Resident scenario Page 19 of the INEER report describes a scenario where 25% of the diet comes from food grown onsite Page 23 of the report describes a subsistence farmer who is technologically advanced to the point where he or she could grow much of their own food, yet be able to devote much of their time to other pursuits The agencies' Rural Resident scenario assumes that virtually all fruits and vegetables come from contaminated soil onsite and that the resident spends as much as 350 days per year, 24 hours per day on site
16	What is the basis for the evident determination by the authors of the Task 3 Report that it is appropriate to assume that site control, institutional memory, and legal land use restrictions will prevail for thousands of years?	The agencies do not assume that institutional controls are likely to last thousands of years It is interesting that the INEER report reveals a dichotomy as to whether there are legal bounds on the living conditions or not, even though the authors state there should not be The implication of a technologically advanced methodology for farming would imply an infrastructure in society through which the technology can be obtained and applied, yet the farmer has the option to do as he or she pleases without any worry of government sanctions To farm this land in this technologically advanced manner would imply the application of soil amendment, deep tilling and use of a reliable, readily available water source This level of sophistication plays against the concept of unchanging contaminant concentrations, and the use of limited shallow ground water for both irrigation and drinking water Instead, this reinforces the idea that it would be reasonable to assume the use of imported water, and suggests once again that the agencies have been overly conservative in the risk assumption that the soil remains at a fixed contaminant level
17	Why do DOE and the regulators assume that calculating RSALs to protect a wildlife refuge worker provides an adequate basis for long-term public health protection? What is the basis for this assumption?	The agencies intend to select RSAL and cleanup levels that fall within the CERCLA risk range for the anticipated land use, which is a wildlife refuge worker It is likely that these selected numbers will also fall within the CERCLA risk range for the Rural Resident scenario The agencies consider these ranges to be protective
18	An RSAL for plutonium calculated to protect a wildlife refuge worker at a 10-6 risk level would fall within the 1 to 10 picoCuries per gram level recommended by IEER Do the agencies expect to set the RSAL at this level? If not, why not?	No See response to comment 17 above
19	Given the postulation of a genetic "uncertainty	There is no risk level associated with this postulate

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	principle," can the agencies demonstrate conclusively that they can protect wildlife over the long-term with an RSAL set at a risk level less protective than 10-6?	The manner in which this postulation is formed would require a different basis for resolution than has been used to estimate the excess risk associated with setting RSAL levels The postulate supposes there is genetic change in a population caused by radiation damage that is not manifested in individual species of the population until essentially the entire population is affected If true, this would imply that genetic changes are inevitable (and unpredictable – "genetic uncertainty", but hardly a "principle") due to radiation exposure The increase or reduction of radiation exposure would only be a means to increase or reduce the rate of such uncharacterized damage in the species By its very nature, this damage would be manifested through a continuous process even in the absence of any influence from residual contamination, because background radiation is contributing at least an order of magnitude greater intensity than is contributed by the residual contamination itself at any of the RSAL levels calculated The necessary conclusion from this examination is that reduction in exposure would serve only to slow the process but would not reduce or in any other way change the risk that the process is ongoing We know of no mechanism for dealing with such uncharacterized temporal risk in the literature, nor is the conjecture of such an approach a constructive use of resources at this time

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